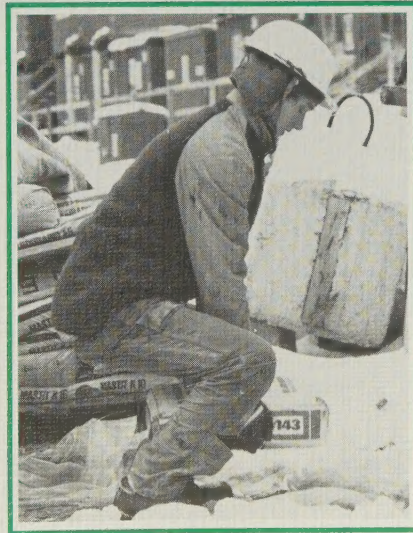


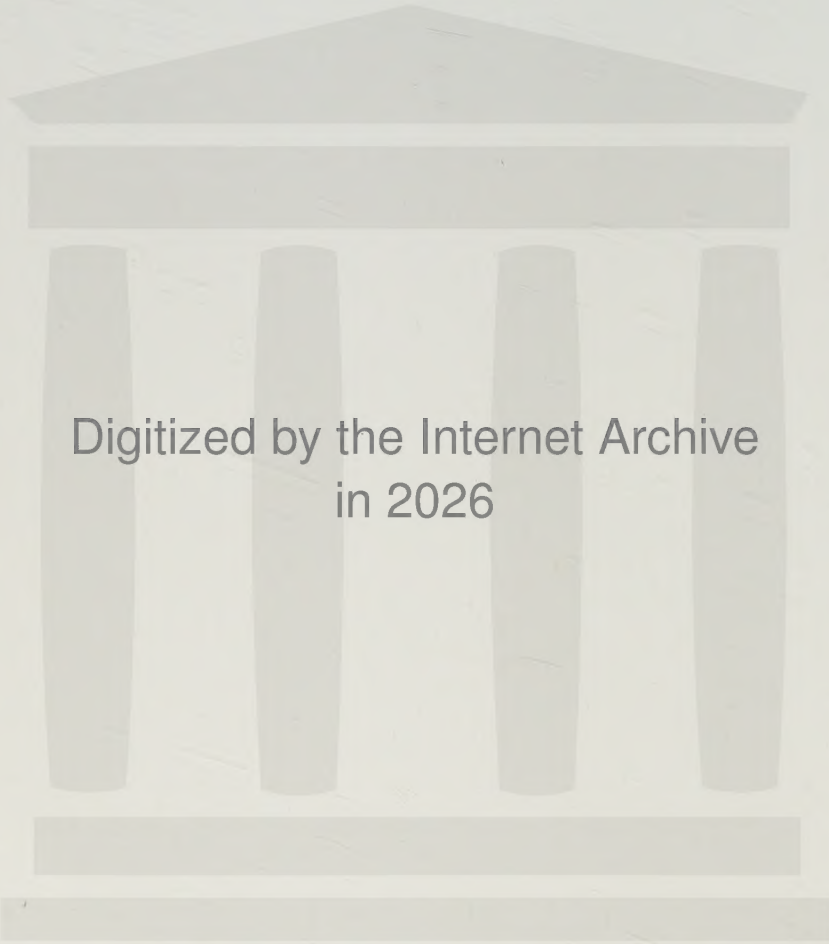
INTRAABDOMINAL PRESSURE AND TRUNK MUSCLE ACTIVITY DURING LIFTING

by

Bertil Hemborg



LUND 1983



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by

Bertil Hemborg
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Akademisk avhandling

som för avläggande av medicine doktorsexamen vid medicinska fakulteten vid Lunds universitet kommer att offentligens för-
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Title and subtitle INTRAABDOMINAL PRESSURE AND TRUNK MUSCLE ACTIVITY DURING LIFTING.		
Abstract Low back pain is a major problem. The aim of this study was to analyse the muscular and pressure responses to loads during lifting in various ways. Twenty male healthy subjects, twenty subjects with chronic low back pain and ten skilled weightlifters performed a series of standardized lifts with and without modification. Simultaneous registrations were made from intraabdominal pressure (IAP), myoelectrical activity of the oblique abdominal muscles, of the erector spinae and - in part of the material - of the puborectalis muscle, from the intrathoracic pressure (IIP) and from respiration. Observations and results: 1) The common characteristics of lifting were described as regards the above parameters, and the diaphragm (by the transdiaphragmatic pressure difference). 2) Leg lifts gave higher IAP values than back lifts in healthy subjects but not in low back patients. The timing of activation differed between the lifting techniques. 3) The patients had a reduced abdominal muscle strength but the same IAP during lifting compared to the healthy subjects. 4) Isometric abdominal muscle training increased the muscle strength, but the oblique abdominal muscle activity and the IAP during lifting did not increase, neither in healthy subjects nor in patients. 5) A weightlifter's belt and a non-elastic support gave a moderately increased IAP but no reduction of trunk muscle activity during lifting in a short-time study. 6) Natural breathing was recorded. None of four tested breathing techniques affected the IAP significantly. 7) The building up and maintenance of IAP during lifting was found to depend on a good coordination between the muscles around the abdomen. The diaphragm is the most important one for IAP level but could be relieved from above, if the airways are closed. -Preventive training should be directed more towards skill of lifting than towards muscle strength.		
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Signature

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Date 17. February 1983

From the Department of Physical Therapy
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INTRAABDOMINAL PRESSURE AND TRUNK MUSCLE ACTIVITY DURING LIFTING

by
Bertil Hemborg

LUND 1983

To
Gertrud
Christina, Susanna, Anders

To
Gertrud
Christina, Susanna, Anders

The present thesis is based on the following papers, which will be referred to in the text by their Roman numerals. In addition, some hitherto unpublished results will be presented.

- I. Hemborg, B., Moritz, U., Hamberg, J., Löwing, H. and Åkesson, I.
Intraabdominal pressure and trunk muscle activity during lifting-effect of abdominal muscle training in healthy subjects.
Scand J Rehab Med: In press.
- II. Hemborg, B. and Moritz, U.
Intraabdominal pressure during lifting in relation to trunk muscle strength in chronic low back patients.
Submitted for publication.
- III. Hemborg, B., Moritz, U., Hamberg, J., Holmström, E., Löwing, H. and Åkesson, I.
Intraabdominal pressure and trunk muscle activity during lifting - effect of abdominal muscle training in chronic low back patients.
Submitted for publication.
- IV. Hemborg, B., Moritz, U., Holmström, E. and Åkesson, I.
Lumbar spinal support and weightlifter's belt - effect on intraabdominal and intrathoracic pressure and trunk muscle activity during lifting.
Submitted for publication.
- V. Hemborg, B., Moritz, U. and Löwing, H.
The causal factors of the intraabdominal pressure rise during lifting, including the effects of respiration.
Submitted for publication.



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I N T R O D U C T I O N

Low back pain constitutes a major medical and socio-economic problem in great many countries. In Sweden low back disorders are the most common cause of sick-listing and sickness pension.

Manual materials handling has been identified as one of the main causes of back trauma and low back complaints, and it continues to be an occupational hazard of serious consequences despite all mechanization (Ayoub 1982). Manual work with frequent heavy lifting has been shown to be connected with an increased occurrence of low back pain among the employees (Chaffin-Park 1973, Snook et al 1978).

Against this background it is evident, that there is an urgent need for prevention against low back pain. This can be principally accomplished in two ways, which should preferably be combined: 1. By changing the methods of work in order to reduce external load and 2. by increasing the individuals' resistance against the harmful effects of external load.

Considering the second approach, abdominal muscle training has been recommended as prevention against low back pain, e.g. in the so-called Back school (Zachrisson-Forssell 1981). The aim of the training is to decrease the load on the lumbar spine at heavy tasks, such as lifting, by increasing the intraabdominal pressure (Morris 1973, Nachemson 1975) or by creating a "muscle corset" (Zachrisson-Forssell 1981). However, it has not been shown, neither physiologically nor clinically that the training works that way.

The intraabdominal pressure is important for the stability of the trunk (Broberg 1981) and for reduction of the load on the lumbar spine (e.g. Davis 1959, Morris et al 1961, Eie-Wehn 1962, Broberg 1981, Schultz et al 1982).

To arrive at methods meeting the great need for efficient prevention we must have a detailed concept on the trunk reaction to load. This investigation is an attempt to elucidate essential mechanisms in this context.

For this purpose we chose to study lifts, as they seem to increase the frequency of low back complaints, as they expose the low back to considerable loads, as they are common in the construction industry and, finally as they are possible to standardize fairly well.

L I T E R A T U R E R E V I E W

During the second half of the nineteenth century, and the first decades of our century several investigations studied the intra-abdominal pressure in animals, cadavers and humans alive with respect to respiratory and circulatory effects (For reviews and references see Emerson 1911, Overholt 1931, and Lam 1939).

Sir Arthur Keith (1923) studied the adaptations of the abdomen to the orthograde posture in man. He stated that the straight and oblique abdominal muscles were primarily muscles of the spine. When the arms no longer assisted in supporting the body but were used for lifting and carrying, the erect trunk had to afford a firm basis of action for the arms. The trunk muscles surrounding the abdominal cavity were then called into action to compress the contents of the abdomen.

In 1931, Grimes recorded the intraabdominal pressure (IAP) during lifting by means of a bag in the colon. In 1956, Davis reported on changes in the IAP during weight-lifting in different postures. During the following years up to now , there are several studies on IAP during lifting. Table I lists these studies and in addition shows other registrations which were made simultaneously with the IAP.

There are, moreover, several studies on the trunk muscle activity during lifting without simultaneous recording of the IAP. (e.g. Floyd-Silver 1951, 1955, Okada 1970, Ekholm et al 1982).

There are only a few studies of IAP with simultaneous recording of the anterior abdominal muscles and the erector spinae muscle EMG activity. Only Kumar (1971, 1980) used quantitative analysis of the EMG but did not include intrathoracic pressure in his studies.

Several authors have made comparisons between the main techni-

Table I. Studies on intraabdominal pressure during lifting.

OA = Oblique abdominal muscles ITP = Intra-thoracic pressure

RA = Rectus abdominis muscle RESP = Respiration

ES = Erector spinae muscle

Authors	Years of publication	Method of IAP recording	Simultaneous recordings					Lumbar support	Training
			EMG			ITP	RESP.		
			OA	RA	ES				
Grimes	1931	Barnes bag in colon				+			
Bartelink	1957	Gastric balloon	+	+			+		
Davis	1959	Gastric balloon + rectal balloon				+	+		
Morris et al	1961	Gastric balloon	+	+	+				
Eie-Wehn	1962	Gastric balloon				+			
Davis-Troup	1964	Gastric balloon				+			
Eie	1966	Gastric transducer							
Davis	1966	Radio pill							
Hamley-Saunders	1968	Radio pill	+	+	+				
Asmussen-Poulsen	1968	Gastric balloon			+				
Kumar	1971	Radio pill	+		+				
Andersson et al	1976	Radio pill			+				
Davis-Stubbs	1977-78	Radio pill							
Kumar	1980	Radio pill	+		+				
Fairbank et al	1980	Intragastric transducer							
Grew	1980	Rectal transducer							
Legg	1981	Radio pill							+
Örtengren et al	1981	Radio pill			+				
Grew-Deane	1982	Rectal transducer						+	
Present study	1983	Gastric, open catheter	+		+	+	+	+	+

ques of lifting, leg lifting and back lifting (e.g. Morris et al 1961) but, none of these studies were performed with quantitative EMG-recordings of the anterior abdominal muscles as well as and the erector spinae.

Most previous studies were made on healthy subjects. Fairbank et al (1980) examined the IAP in a group of twenty-three patients with chronic low back pain who were asked to lift a weight of 5-10 kg a few centimeters off the floor. The study did not include recordings of EMG.

Legg (1981) studied the effect on the IAP of abdominal muscle training with dynamic sit ups, and, in addition, the effects of exhaustion of the abdominal muscles. The myoelectrical activity was not recorded.

The effects of different kinds of lumbar support has been studied in various situations. Morris et al (1961) recorded trunk muscle activity, intraabdominal pressure and intrathoracic pressure at rest and in static loading. Nachemson-Morris (1964) studied the intradiscal pressure in standing, and Waters-Morris (1970) the trunk muscle activity in standing and walking. There is, so far, only one study on the effects of lumbar supports when lifting (Grew-Deane 1982), including IAP but no EMG recordings.

There are some previous observations (see table I) about respiratory effects on the intraabdominal pressure during lifting but no systematic analysis.

The intraabdominal pressure rise during lifting was by several authors (e.g. Morris et al 1961, Grillner 1978) regarded to be due to a reflex mechanism, but the nature of this reflex was not clearly understood. Kumar (1971) and Kumar-Davis (1973) analyzed the afferent part of this hypothetical reflex. There is, to our knowledge, no investigation concerning the factors responsible for the building up and maintenance of the IAP rise during lifting.

Thus, there is a rather large bulk of data concerning the intra-abdominal pressure and trunk muscle activity during lifting. However, several questions remain to be answered to get a full picture of the trunk muscle and pressure responses to load when lifting.

AIM OF THE PRESENT INVESTIGATION

The aim of this investigation was to answer the following questions:

1. What are the main characteristics of lifting with regard to intraabdominal pressure and trunk muscle activity?
2. What is the difference between leg lifts and back lifts with regard to intraabdominal pressure and trunk muscle activity?
3. What is the difference between chronic low back patients and healthy subjects with regard to intraabdominal pressure and trunk muscle activity during lifting?
4. What effects are obtained from abdominal muscle training on these parameters in healthy subjects and in chronic low back patients?
5. What are the immediate effects of lumbar spinal supports and weightlifter's belts on these parameters in chronic low back patients and in weightlifters.
6. How does various breathing techniques affect these parameters?
7. What factors are responsible for the building up and maintenance of the intraabdominal pressure rise during lifting?

S U B J E C T S

Three separate groups took part in this investigation (table II).

Healthy subjects

The first group of twenty healthy male subjects with no history of low back pain was selected from employees in the building trade. They were all electricians and physically comparatively inactive in their leisure time. The reasons for this principle of selection were first, that their exposure to loads, both at work and leisure, should be as similar as possible and secondly, that with such subjects the greatest possible effect of muscular training could be expected.

Subjects with chronic low back pain

The second group of twenty subjects was also selected from construction workers, with the intention to get a group that was as similar as possible to the healthy one except for their chronic low back disorders. Using the unions' lists of members and the previous case records from our medical health center we picked out those men who had most complaints from the lumbar region but were yet able to carry out the programme. They had had more or less continuous low back pain without sciatica for 2-18 years (median value 5.5 years) with aggravation by heavy work or by protracted static posture. On examination we found local tenderness and suspected instability in the lumbosacral and/or the adjacent lumbar segments. Twelve out of twenty subjects stated that they tried to be careful and avoided heavy lifts. Five men had been sicklisted during the last year, one had changed work due to back pain. Despite these complaints they had apparently learnt to live with the pain. Although they are often called "patients" in these studies it should be noted that they were not under medical care at the time and thus not

patients in the proper sense of the word. Out of the twenty subjects in this group thirteen were electricians, four were carpenters, two supervisors and one was a painter.

Weightlifters

The third group of ten volunteers was selected from weightlifters who were considered to be very skilled, as we wanted to examine their technique of lifting, both when lifting the same weights as the other two groups, and when lifting bar-bells in their own way (to be reported elsewhere). They had been practising weightlifting for 2-12 years, most of them intensively. Three men were national champions in their respective weight classes. Four of them were students, two workers, two engineers and two teachers.

Five of the weightlifters, reported previous intermittent or slight low back complaints except for the last year. One of them reported that his pain occurred when he was playing the piano but not during lifting! One subject had slight pain during the study, but was still able to train and work.

Apart from the back findings in the patient group, routine examination of the back, hips and other joints, and other routine tests were quite normal in all cases. There were no signs of abdominal, cardiac or pulmonary disorders. None had a suspected inguinal hernia.

Spinal flexion and straight leg raising were tested in the healthy subjects and in the patients. Spinal flexion was assessed by measuring the increase of distance C7-S1 from standing erect to bending forward and the distance between fingertips and floor during maximum forward flexion (American Academy of Orthopaedic Surgeons 1980). In the straight leg raising test the angle between the table and the straight leg was measured with a goniometer. No marked differences were found between the groups (II, table II).

One of the healthy subjects and eight of the low back patients had had some instruction in lifting technique. Before the examination the healthy subjects and the patients were instructed in leg lifting, so that they all had roughly the same information. The weightlifters were all, of course, well trained in their special technique of lifting bar-bells.

One of the patients had been using a corset in leisure time for six years, and another a weightlifter's belt for six months. All the weightlifters generally used leather belts for the heaviest training and at competitions.

Altogether, the 50 subjects who took part in this investigation performed about 3000 lifts in our laboratory, including about 200 lifts with bar-bells to be reported elsewhere.

Table II. Characteristics of all the subjects in this investigation.

	Healthy subjects	Low back patients	Weightlifters
Participation in studies:	I, II, V	II,III,IV,V	IV, V
Number	20	20	10
Age (years)			
mean	28	32	23
range	23 - 33	22 - 37	18 - 28
Height (m)			
mean	1.80	1.80	1.74
range	1.71-1.87	1.74-1.88	1.61-1.88
Weight (kg)			
mean	75	76	80
range	65 - 85	57 - 89	58 - 123
Duration of low back pain (years)			
median	-	5.5	•
range	-	2 - 18	
Duration of practising weightlifting (years)			
median	-	-	6.5
range	-	-	2 - 12
Other physical activities in leisure during last 3 months prior to study.			
None	12	18	7
Physical activity 1-3 h/week	6	2	3
Soccer/football (amateurs)	2	-	-

• see text.

METHODS

1. Assessment of trunk flexion strength

- a) *Measurement in the upright position* was carried out in two ways.

In study I the subjects were placed with the back against wallbars and the recording was made by means of a Salter balance (I, fig. 1). In studies II and III a special frame was constructed with a support behind the pelvis, which enabled the subjects to stand more erect, and the recordings were made by means of a strain-gauge. (II, fig. 1).

In both instances the strap of the recording instrument was placed firmly across the chest and upper arms at the level of the attachment of the deltoid muscles. To permit comparisons, the measurings were carefully standardized, including the position of the bare feet in relation to the wall-bars or the frame. The subjects were told to do an attempted flexion and not a hip flexion and their minute movements during the test were supervised. Each subject had to do three maximum attempted flexions with a duration of at least 3 seconds. The estimates were then made from the median values.

To determine which muscles were responsible for the trunk flexion the bilateral motion axis during our test procedure was calculated in one subject. Regarded mechanically as a rigid body, the thoracic cage was supplied with three pointers attached to the skin over the sternum, and the subject was asked to perform the attempted trunk flexion test used in this study. The test was filmed from the side and the minute angular motion of the pointers calculated from the film and accordingly the bilateral motion axis. During our test the axis was found to be located about the intervertebral disc L3-L4. If the subject instead of flexing the trunk did a hip flexion with straight back his motion axis was found to be located about the hip joint, as expected.

- b) *Scoring* according to Janda (1977), without fixation of the feet, was used in study I. It proved unsuitable in these healthy young men, who already before training achieved the highest value in 16 out of 20 cases.

2. Assessment of trunk extension strength

Measurement of the strength of the trunk extensors was performed with the same methods as described for the trunk flexors, during study I and studies II-III respectively, except that the subject faced the wall-bars or the frame with the strap placed across the dorsal part of the chest and the upper arms at the same level as before.

Here, also the bilateral axis of motion was calculated with the above technique. It was found to be situated ventrally to L1-2 during our trunk extension test.

3. Pressure recording

The recordings of intraabdominal (i.e. intragastric) pressure (IAP) were included in all studies (I-V), and those of intrathoracic (i.e. intraoesophageal) pressure (ITP) in studies IV-V. The recording system was based on open polyethylene catheters, filled with fluid (isotonic saline) but without balloon or continuous flow.

The subjects were not allowed to eat during the hours before the examination. After local anaesthesia by spray (Lidokain), three thin polyethylene catheters (Portex PP 100 with an inner diameter of 0.86 mm), fused distally, were introduced through the nose to the upper part of the stomach, guided by the respiratory pressure changes. The distance between the cathetertip and the nostril was noted so that, at repeated examinations, the catheter could be placed in the same position. One catheter was open at the distal end and intended for IAP-recordings. Whenever wanted, the second one had an opening 25 cm proximally, resting in the oesophagus. The third catheter contained air and was intended only as a guide. By three way stopcocks the recording catheters were connected

to pressure transducers (Siemens 746/5 in (study I and part of study II), Bentley Trantec in studies II-V) at the level of the iliac crest. In the first case the signals were transmitted to an electromanometer (Siemens 863) for subsequent recording on Mingograph 82 (Siemens-Elema). In the second case the signals were transmitted to a pressure amplifier (BM Elektronik, Åhus, Sweden) for subsequent recording on magnetic tape (Racal Store 14 FM) and visual control of the pressure curves on Mingograph 82. Thus, in both cases the records were continuously checked on the mingograph for technical interference such as blockage, and the catheters were flushed with saline when necessary.

Static and dynamic calibration

A static calibration of the transducers was done each day against a variable fluid column that was connected to the stopcock.

A dynamic calibration was performed according to Asmussen, Lindström and Ulmsten (1975). The distal end of the catheter (length 1.50 m) was placed in a fluid-filled pressure chamber connected to a rubber balloon. The pressure was increased by means of a pump to about 13 kPa and 20 kPa respectively. The balloon was burst and the pressure instantaneously fell to zero (open air pressure). Duplicate recordings showed that the rise time (= the fall time) was 15 msec., the settling time 100 msec. and the overshoot about 26% (fig. 1). The source of error due to the difference between 37° and the room temperature (28°) during the test was considered small and thus disregarded. During the lifts under consideration the minimum rise time of the IAP was found to be 100 msec. (mostly much more). The rise time of the measuring system must be less than a third of the rise time of the physiological event to assure an acceptable measuring accuracy. Thus, our pressure recording system was considered reliable for this investigation.

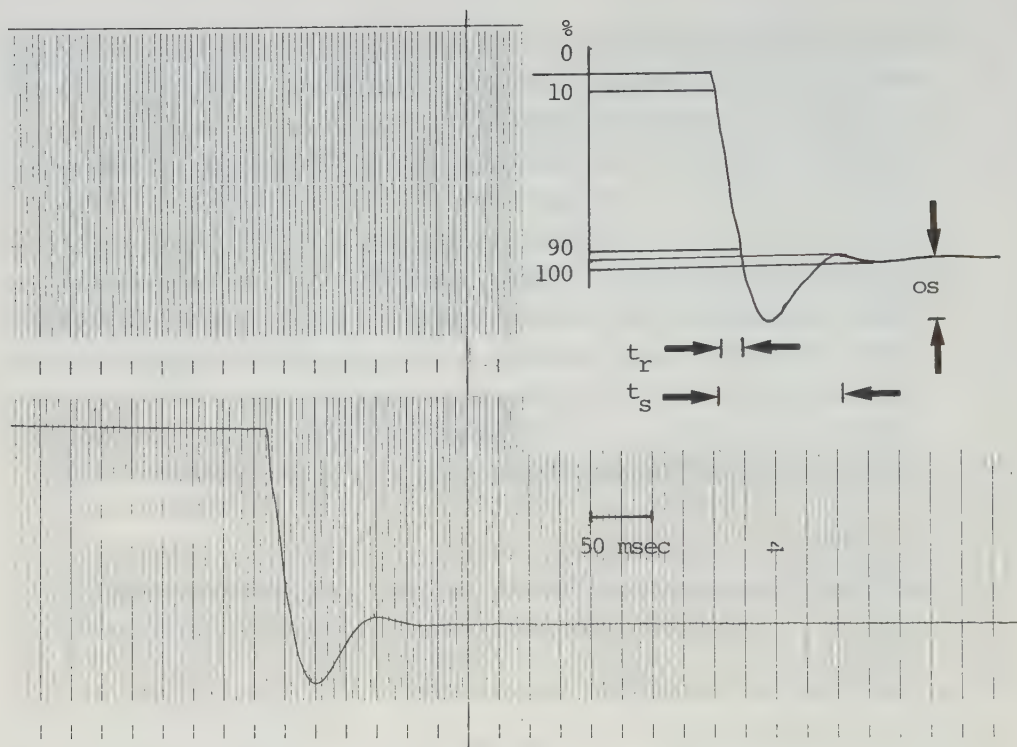


Fig. 1. Dynamic calibration of the pressure recording system.

Rise time = fall time (t_r) is the time required for the response to go from 10 to 90 per cent of its final value.

Settling time (t_s) is the time required for the oscillation of the response to decrease to less than a specified percentage of its final value, here 5 per cent.

Overshoot (os) is calculated in percentage of the final rise or fall.

Test of the intraoesophageal pressure recording.

Another question was, whether our system with fluid containing catheters without balloons could be trusted when measuring positive pressures in the narrow oesophagus, considering the risk of blockage. A series of experiments was therefore performed on four men and one woman with exactly the same recording system as during the investigation. The men's ages were 25-29 years (mean 27), heights 1.70-1.85 m (mean 1.80) and weights 62-82 kg (mean 74 kg), and were thus fully comparable to our subjects. The corresponding values for the woman was 29 years, 1.65 m and 57 kg. The subjects were as-

ked to make a maximal Valsalva manoeuvre against a closed mouthpiece connected to a calibrated air filled pressure recording system. The nose was closed with a springholder. On a cathode ray oscilloscope screen the mouth pressure and the intraoesophageal pressure were simultaneously recorded on the Y- and the X-axis, respectively, and the curves photographed, (fig. 2). In all four males an excellent linear correlation was found up to their maximum pressures of 11.7, 14.7, 16.6 and 19.6 kPa, thus implying that the pressure recording system could be considered reliable also in this "in-vivo" situation. As for the woman there was a good correlation up to 4.9 kPa after which the curve deviated due to some partial blockage of the intraoesophageal pressure, perhaps due to the oesophagus being pressed against the opening of the catheter or, less probable, to air bubbles in the catheter. This possibility of mucosal blockage should be taken into consideration and be further studied in planning to use this pressure recording system in slender subjects.

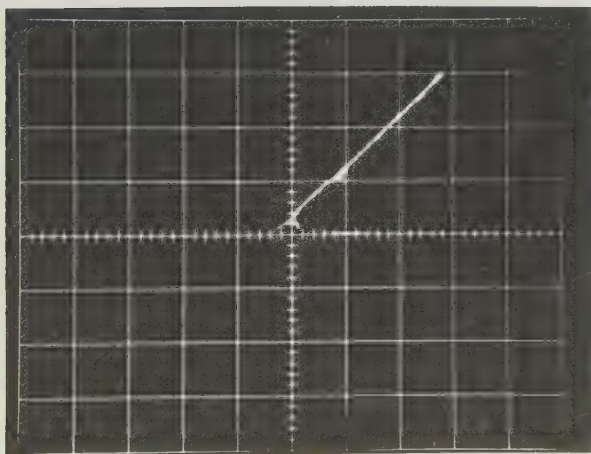


Fig. 2. In vivo test of the ITP recording system. Simultaneous registration of the intraoesophageal pressure on the X-axis and the mouth pressure on the Y-axis during the Valsalva manoeuvre. 1 degree = 10 cm H₂O = 0.98 kPa. For further explanation see text.

Test of the intragastric pressure recording.

The stomach usually contains both fluid and gas. To test if it made any difference whether the tip of the catheter rested in fluid or in gas, we made a series of tests using a stomachlike plastic container filled with equal parts of water and gas. We could find no mesurable difference when the model was exposed to repeated sudden pressure increases of the same magnitude.

X-ray control.

In one volunteer we studied the position of the tip of the catheter, supplied with a small shot of lead. It could be shown that the tip remained at the same level after repeated kneeling, bending over and lifting. This finding could also be confirmed during the experiments by comparing the pressures before, during and after each test series, when standing at ease.

From the X-ray we also calculated the source of error due to the external location of the transducer (dorsolaterally to the iliac crest).

The pressure values were then corrected slidingly considering the variable hydrostatic differences between the catheter tips and the transducers during the lifts.

4. Electromyographic recording

Surface electrodes were used for the oblique abdominal muscles (studies I-V), the erector spinae muscle (studies I-V) and the lateral vastus muscle (study I). Bipolar fine-wire electrodes were used for the puborectalis muscle (study V).

On the healthy subjects we used disposable electrodes 45037 YEH019 Siemens-Elema, with an interelectrode distance of 3 cm. On the two other groups we used disposable electrodes 3M Red Dot 2247 Ag/AgCl, which were safer to handle. Due to their size it was, however, found necessary to increase the interelectrode distance to 5 cm. For this reason we never

made any quantitative comparisons between the groups.

As for the oblique abdominal muscles the electrodes were placed, in all instances, at umbilical level and above the ventral iliac spine. The electrodes over the erector spinae muscle were always located at the L2-3 level and over the most prominent part of the muscle when contracted in hyperextension in the prone position. The electrodes over the lateral vastus muscle were placed with the lower electrode 15 cm above the lateral joint interval. The recording of this last mentioned muscle activity, performed just to control the technique of lifting, was done in the healthy subjects and was substituted by an electrogoniometer on the left knee in the patients and in the weightlifters.

The direction of the surface electrodes was, in all instances, parallel to the muscle fibres. The skin was prepared with sandpaper and alcohol.

Concerning the puborectalis muscle the myoelectrical activity was recorded by insulated bipolar fine-wire electrodes (Nikrotal LX 0.05 mm in diameter) from which about 3 mm of the insulation had been burnt off. They were prepared according to Basmajian (1974) with the modification that the two electrodes were inserted with two separate carrier needles. Guided by an index finger in the ampulla recti the two needles, dorsolaterally from the anus, were put through the ischiorectal fossa to, but not into, the puborectalis muscle, the most prominent part of levator ani muscle. After withdrawal of the needles, the two hooked and bared wire ends were located close to the lower margin of the muscle, about 1 cm apart. By spring-wire coil connectors and screened cables the electrodes were connected to preamplifiers fastened to the subject's waist.

In the healthy subjects in studies I and II the myoelectrical signals of the oblique abdominal muscles were transmitted to a preamplifier at the waist with a tenfold amplifi-

cation, otherwise the signals went directly to the universal amplifier Siemens 854. The myoelectrical activity was recorded on Mingograph 82 both as raw EMG and as integrated EMG. The integration was done with Siemens Integrator EMT 43 B over a preset period of 0.3 s.

In the patients in study II and all subjects in studies III-V, preamplifiers, fastened to the subject's waist, were used for all myoelectrical signals. After further amplification (BM Elektronik, Åhus, Sweden) the signals were stored in analogue form on magnetic tape. The upper and lower cut-off frequencies were 1000 and 50 Hz respectively. An active T-filter with a slope of 12 dB/octave was used. During recording the signal quality was continuously checked on a mingograph. For analysis, the myoelectrical signals were full-wave rectified and integrated over a preset period of 0.1 s., each containing 400 readings.

5. Respiration recording (in study V)

A new flow-meter was constructed to record the respiratory flow without motion artefacts (Bengt Månsson, BM Elektronik, Åhus, Sweden). It is based on the vortex principle and consists of a tube, a mouthpiece, an ultrasound unit and a termistor. Inside the tube, on either side of the unit, is a triangular shaped pole that converts the straight air flow into a turbulent one. The turbulence is detected by ultrasound across the tube and the result will be a pulse frequency proportional to the air flow. The termistor tells whether the air is passing in or out, and the signals from the ultrasound unit give the volume passing per time unit by integration.

6. The lifts

Lifts were done with "back lifting" (II, fig. 2) and "leg lifting" (I, fig. 3) in all studies. In addition to these symmetrical lifts, the subjects in study III were asked to do a "leg lift B" (for this reason the ordinary leg lift was called "leg lift A" in study III).

By "back lifting" is meant symmetric lifts with straight knees and bent back. The ordinary "leg lift" ("leg lift A") is a symmetric lift with the feet placed behind the box, the knees flexed and the back as straight as possible. In these two lifts the position of the feet is the same in relation to the box to be lifted.

The third mode ("leg lift B") was advocated by Davies (1972) as a "new way to lift" (III, fig. 2). The main point is that the feet should be far enough apart to give a balanced distribution of the weight. The leading foot should point in the direction of the movement, the knees and hips should be bent and the back kept as straight as possible. The position of the feet makes it easier to keep the heels on the ground, while the ordinary leg lift often forces one to balance on the forefeet. One can, moreover, come closer to the burden in leg lift B.

The lifts were performed from floor level to the upright position with the load on extended hanging arms in front of the body.

Each subject could choose his own lifting pace. Otherwise the lifts were carefully standardized to facilitate comparisons. A physiotherapist gave instructions about the technique to be used. Each lift was done twice and the subjects were allowed to rest between lifts.

In all lifts, a specially made box was used, 40x25x16 cm, with symmetrical handles 11 cm above the floor. (II, fig. 2). The box could be loaded symmetrically with 5 kg weights, and was supplied with an accelerometer for recording vertical acceleration and deceleration. For the patients in study II and in all lifts in studies III-V, a switch was also attached to the box for recording lift-off and touch-down. Another switch was then placed behind the subjects at the Th3-4 level when standing erect, recording the end of the lifting and the start of the lowering. For the healthy subjects in studies I

and II we determined these times by the accelerometer curves.

As mentioned above, an electrogoniometer was attached to the left knee for recording the lifting movements in the patients (study II) and in all subjects in studies III-V (IV, fig. 4 gives an example of recording).

Finally, certain lifts were recorded on super-8-film or on videotape.

7. Isometric training of the abdominal muscles.

All the subjects were asked to perform a programme of intense abdominal muscle training during five weeks. The results of the healthy subjects are reported in study I, and of the patients in study III. Some of the patients and weightlifters were also evaluated more comprehensively in study V as to the differences after training.

Everyone had detailed personal instruction in the standardized technique to be followed and was checked twice a week throughout the period.

The initial position was supine, with hips and knees flexed, the heels supported, and with active plantar flexion of the feet. The back was pressed against the floor and the gluteal muscles were actively contracted. The training procedure was as follows: The subject breathed out and held his breath, after which he curled up until he experienced a maximal effort, though without changing the position of the pelvis. This posture was held for a pre-set time.

Each exercise was performed twice daily, with 10 curl ups on each occasion. The subjects kept records of the daily training. The load and holding time were raised successively by the physiotherapists. This was done both by extending the holding time to 15 seconds and by increasing the external torque through the position of the arms, as the subjects grew stronger (I, fig. 6).

8. The lumbar spinal support and the weightlifter's belt (IV, fig. 1 a + b).

A specially designed support was made of flexible, non-elastic syrlon, a thermoplastic material, 2 mm in thickness with holes for the screened cables from the electrodes (Gert Karlsson, Camp Scandinavia AB). The support was supplied with an extended anterior section and shaped to fit in with the low back and with the interspace between the lateral costal arch and the iliac crest. The support, made in three sizes, consisted of two parts joined together by strings and clasps. The subjects were asked to tighten the support firmly but yet comfortably enough to be used all day at work. The strings were graded and each subject performed all lifts with the same tightness.

The weightlifter's belt was made of leather, 3 mm in thickness somewhat broadened dorsally but on the whole narrower than the other support, especially anteriorly. The belt was made in three different sizes. When used it was tightened according to the same guidelines as those used for the lumbar spinal support.

9. The examination procedure

Before and after abdominal muscle training the subjects were put through a standardized test programme, in which the strength of the trunk flexors and extensors was recorded and a series of lifts was carried out. The healthy subjects and the patients lifted 0, 10, 25, and 40 kg, and the weightlifters 0, 25, 40, and 55 kg.

In addition to the basic programme aimed at studying the effects of training, the subjects were asked to do a number of lifts with modifications. Table III lists the different purposes of this extended programme. Concerning the effects of lumbar supports, weightlifter's belts and different breathing techniques we always compared the same subject with and without modifications. It should be pointed out that table III gives the number of subjects and lifts to be compared in.

each study. As some lifts appear in more than one comparison, the number of lifts compared exceeds the total number. As for the recordings of natural breathing these lifts were performed outside the ordinary programme, as they were not comparable to other lifts without the respiration recording apparatus.

Table III. Survey of the number of subjects and lifts included in each part of the investigation. The number of lifts in each square refers to all lifts before and after training, with and without a support, and all tested breathing techniques respectively. For further explanation see text.

Aim of study	Study	Healthy subjects		Low back patients		Weightlifters	
		No Subjects	No Lifts	No Subjects	No Lifts	No Subjects	No Lifts
Effect of abdominal muscle training	I,III,V	20	480	18	648	5	100
Comparison patients/healthy subjects	II	20	200	20	200		
Effect of lumbar support and weightlifter's belt	IV			20	400	10	60
Effect of different breathing techniques	V	20	480	20	320	10	80
Recording of natural breathing	V	-	-	20	69	10	56
Assessment of causal factors of IAP	V	3	54	3	36	5	69

The Mueller manoeuvre was done routinely by the patients and the weightlifters. After an ordinary expiration when the subjects were supposed to be roughly at the position of functional residual capacity (FRC) they were asked to perform a maximum diaphragmatic inspiratory effort with the mouth and nose closed. Before the test the subjects had, during the attempted inspiration, practised pushing the abdominal wall outwards, avoiding rib cage expansion. During the Mueller manoeuvre we determined the maximum transdiaphragmatic pressure (P_{di_max}), which was then correlated to the peak IAP during the lifts.

As for the assessment of the causal factors of IAP we performed an extended study with three healthy subjects including the recording of the myoelectrical activity of the puborectalis muscle, the most prominent part of the levator ani muscle.

Fig. 3 gives a schematic view of all the methods used in different parts of this investigation. As for the healthy subjects in studies I and II the computer was omitted and the video camera was substituted by a super-8-film camera. For further details about the methods and procedures see the separate papers I-V.

The subjects were asked to report any pain during or after a strength test or a lift. If there was any fear that the pain should prove too severe, that particular test or lift was excluded, to avoid all risks.

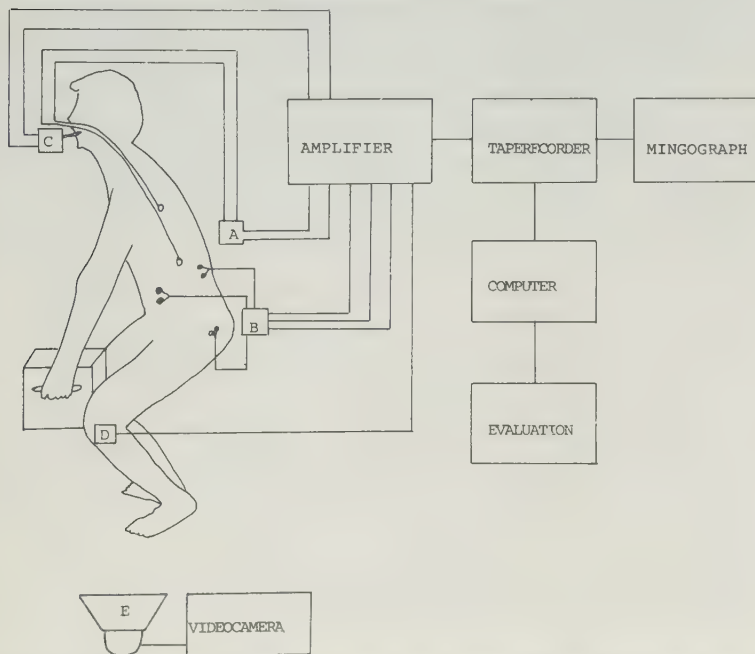


Fig. 3. Schematic view of the recordings used in different parts of this investigation. For details see text. A. Pressure recording system. B. EMG recording system. C. Respiration recording unit. D. Electrogoniometer. E. Video camera.

10. The evaluation procedure.

The following parameters were registered during each lift done by the healthy subjects in studies I and II: 1. myoelectrical activity of the oblique abdominal, erector spinae and lateral vastus muscles. 2. IAP and 3. acceleration of the weight box. The signals were registered on a mingograph. The curves thus obtained were used for manual calculation of the following data for each experiments: Start and end of lifting and lowering of the weight, peak IAP and the concomitant values of the integrated EMG activity during 0.3 s., the exact times for the peak IAP and for the maximum EMG activities of the three muscle groups under study as well as the exact time for start and end of the erector spinae muscle activity during both lifting and lowering of the weight. All the times were then determined in relation to the total times of liftings and lowerings.

For the remainder of the lifts the analogue signals from the EMG of the oblique abdominal and the erector spinae muscles, from the IAP and ITP, from the electrogoniometer, and from the accelerometer were simultaneously recorded and stored on magnetic tape (Racal Store 14FM) with the signals from the switches giving the starting points and endings of the liftings and the lowerings. The same applied to the EMG of the puborectalis muscle and the respiration recording, when performed. All information was then put into a computer where the myoelectrical signals were full-wave rectified, and integrated over preset periods of 0.1 s., each containing 400 readings. The other signals were all averaged over the same periods of 0.1 s. and converted digitally. The registrations comprise the periods from 0.5 s. before the lift-off to the end of the lifting and from the start of the lowering to 0.5 s. after the touch-down.

For these lifts, where the calculations were computerized, we also recorded the analogue signals on a mingograph. This was done primarily to check the signal quality and the function of the tape-recorder. The records were also found to be

very useful in the analysis of the data.

For the strength tests the values from the Salter balance (study I) and from the strain-gauge (studies II-III) were recorded manually. Registrations were also made from the muscles and the intratruncal cavities in the same way as for the lifts. The calculations were based on the maximum activity in the tested muscle during three consecutive 0.1 s. periods (or one period of 0.3 s.). The activity of the antagonist and the IAP were read off for the same 0.3 seconds.

During the Mueller manoeuvre (study V), we determined the maximum transdiaphragmatic pressure (Pdi_{max}), which was then correlated to the peak IAP during the lifts.

As for the assessment of the causal factors of the IAP during lifting (study V) we made an analysis of the 140 graphs illustrating lifts with 25, 40, and 55 kg by the three groups of subjects. We then compared, on the one hand, different subjects doing the same lift and, on the other hand, one subject lifting the same load twice with the same technique but with different muscular responses and pressures.

11. Statistical methods

The design of the study was chosen to get a matching situation where each subject could serve as his own control. This approach was considered essential on account of the great interindividual variations in the variables studied.

Throughout the investigation all lifts were performed twice and the calculations were made from the mean values of the two lifts.

In studies III-V the analysis of significance of differences was extended and carried out throughout the whole lifting procedure by calculating the 95% confidence limits of the

mean difference between values with and without modification of the lifts. As the time varied between lifts, the time was then normalized and expressed as percentages of the whole time, and for lifting and lowering separately, it runs from 0 to 100%. The mean values with and without modification were illustrated graphically with the confidence limits of the mean difference. This meant that a certain type of lift could be compared easily before and after training, with and without a belt or with and without a specified breathing technique. When the mean values after modification were outside the confidence limits, the values after differed significantly from the values before modification ($p < 0.05$).

Otherwise routine statistical methods were used. The analysis of significance was carried out according to Student's t-test. The strength of the covariance was determined by Pearson's correlation coefficient, r .

RESULTS

1. The lift

The following common characteristics were found in all the lifting experiments.

a) *Intraabdominal pressure during lifting.*

The IAP shows a characteristic variation for the type of lifts studied. In the beginning of the lift the pressure rises more or less steeply to a peak, after which it descends to a level at or immediately above the pressure in the upright position without load, although the subject is now holding a load of varying weight in his hands. The curve varies between the subjects and in one subject between lifts with different weights, as regards the height of the peaks and their position in time, but the shape of the curve remains practically the same in all lifts of the same type (I, fig. 4 and 5).

During the lowering, the pressure rises comparatively slower to form another peak before the touch-down, whereupon the pressure quickly returns to its basal level. The values are generally somewhat lower during lowerings than during liftings.

The average peak IAP values at lifting rise almost linearly with the increase of weights (II, fig. 3 a + b). This is also true for most of the individuals, but on different levels (I, fig. 9 a + b, and III, fig. 8 a + b). The figures also show that some subjects had a high peak IAP with all loads, while others often had low ones with the same external loads. The average peak IAP values were 3.1 kPa with 10 kg, 5.8 kPa with 25 kg, and 10.2 kPa with 40 kg. For the healthy subjects and the patients, the coefficients of variation were 59 and 59% respectively with 10 kg, 44 and 52% with 25 kg, and 34 and 42% with 40 kg.

In contrast to the great variations between the subjects there was a smaller variation within duplicate lifts by the same subject. The error of method (SD) was 1.0-1.3 kPa at all groups, techniques, and loads.

In three healthy subjects and in two weightlifters we were able to record the peak IAP at intervals of two years. The values were found to be fairly constant. Those who were "high-pressurizers" or "low-pressurizers" at the first trial seemed largely to remain so.

- b) *The oblique abdominal muscles during lifting (studies I-V).*
The oblique abdominal muscles were more or less active throughout the liftings and lowerings, but the patterns of activation differed with the technique of lifting used (see below).

The myoelectrical activity usually increased with an increase of external load (I, fig. 7). For all weights, the muscles were, however, only slightly activated, by 5-15% with 25 kg lifts and by 15-25% with 40 kg lifts out of maximum activity during the trunk flexion strength test.

- c) *The puborectalis muscle during lifting (study V).*
The puborectalis muscle was always found to be activated during lifting irrespective of the technique used. The activity was generally less at lowering than at lifting. It should also be mentioned that high activity was recorded during the trunk flexion and trunk extension strength tests, during the Valsalva and Mueller manoeuvre and usually during deep expiration but not during deep inspiration. There was no detectable activity at rest, whether standing or sitting (sensitivity 125 - 250 $\mu\text{V/cm}$).
- d) *The diaphragm during lifting (study V)*
The function of the dome-shaped diaphragm was studied by calculating the transdiaphragmatic pressure difference (Pdi). When the diaphragm is relaxed, Pdi is zero. When it is ac-

tivated or passively stretched, Pdi rises and the values are proportional to the tension of the diaphragm and inversely proportional to the radius of the dome, according to the Laplace law. (Grimby et al, 1977).

Pdi_{max} during the Mueller manoeuvre is considered to reflect the strength of the diaphragm (Roussos et al 1977, Gibson et al 1981). After an ordinary expiration when the subjects were supposed to be roughly at the position of functional residual capacity (FRC) they were asked to perform a maximum diaphragmatic inspiratory effort with the mouth and nose closed. Before this, the subjects had, during attempted inspiration, practised pushing the abdominal wall outwards, avoiding rib cage expansion.

A strong positive correlation was found between the peak IAP and Pdi during the lifts (V, table V) in the patients and the weightlifters (the healthy subjects were not included). This correlation could also in many instances be shown during the whole lifting (V, fig. 5-8).

A positive correlation was also found between the peak IAP during the lifts and Pdi_{max} during the Mueller manoeuvre in the patients (V, table IV).

The highest Pdi due to passive stretching of the diaphragm was found to be about +1 kPa about FRC and about +2 kPa at maximal expiratory level (Bouhuys et al 1966). Higher values may then be dependent on muscular activity of the diaphragm.

The average Pdi_{max} was 10.4 kPa (SD = 4.2) in the patients and 8.3 kPa (SD = 4.1) in the weightlifters. The average Pdi coincidental with the peak IAP increased with an increase of external load from 2.5 kPa at 10 kg to 8.7 kPa at 40 kg in the patients and in a similar way in the weightlifters.

During lowering the average Pdi values were quite equal to

the corresponding values during lifting.

In summary, this may imply that the diaphragm was activated during the lifts and that the activity increased with an increase of external load. In addition, the IAP level seemed to be dependent on the activation of the diaphragm.

- e) *The intrathoracic pressure during lifting (study IV and V).*
The intrathoracic pressure (ITP) showed great individual variations (V, fig.9). The pressure was either negative throughout the lift, or rose successively from negative to positive values during the lift, or it was positive throughout the lifting procedure.

A positive ITP during lifting was always concomitant with the subject holding his breath.

For both patients and weightlifters who breathed during lifting there was no definite correlation between the breathing volumes and the ITP.

There was, moreover, no correlation between the peak IAP and the simultaneous ITP in the patients. On the other hand, there was a significant correlation in the weightlifters when lifting with 25, and 40 kg ($r = 0.77-0.86$, $p < 0.05$), and when lowering with 40 kg ($r = 0.76-0.80$, $p < 0.05$).

- f) *The erector spinae during lifting*

The erector spinae muscle, as reflected by the myoelectrical activity under the electrodes at the L2-3 level, was always more or less activated during the leg lifts and during part of the back lifts (see below).

The activity generally increased with increased external loads (I, fig. 10). With 25 kg, the average maximum activity was 40-60% of the maximum recorded during the trunk extension strength test. For 40 kg the corresponding figure was 50-75%

2. Back lifting versus leg lifting.

Back lifting and "ordinary" leg lifting (leg lift A) were compared in all studies, especially in studies I-III. Besides, another type of leg lifting (leg lift B) was added in study III.

As regards the first two types it should be noted that the subjects were to place their feet in the same position relative to the box, while they for leg lift B were to place their feet apart with the right foot at the side of the box (III, fig. 2). This should reduce the lever of the box but also make the lift somewhat asymmetrical. In a pilot study we tested the *bilateral myoelectrical activity with leg lift B* but could find no measurable difference for the oblique abdominal and the erector spinae muscles.

Considering in the first place *the two lifts A and B*, there were no significant differences in the IAP, ITP or the myoelectrical activity of the oblique abdominal and the erector spinae muscles. This is true also for the puborectalis muscle which was examined in three subjects. Beside the programme in study V they were asked to lift 25, and 40 kg with the two leg lifts. Different patterns of activation were found between the subjects but no clear difference between the two techniques.

Considering in the second place *the back lifts and the leg lifts*, the differences and similarities are illustrated in study I (fig. 4, 5, 7, 8, 9, 10, and 11) and in study III (fig. 5, 7, and 8).

The peak IAP was higher during leg lifts than during back lifts in the healthy subjects ($p < 0.01$ in all instances). This was not the case in the low back patients, whether the calculations were done on the peak IAP or on the average values during the whole cycle. Seemingly the gap in IAP between the two types of lifts found in the healthy subjects was obliterated in the patients by higher pressure at back

lifts and lower pressure at leg lifts, averagely.

In both groups there was, however, a clear difference between the two lifts as regards the shapes of the average curves and the times of the peak IAP. In the leg lift, the IAP rose soon after lift-off and reached its peak value during the first half of the lifting time. In back lift the IAP generally rose more gradually up to the peak IAP soon after the middle of the lift.

As for the *oblique abdominal muscles* the process was the opposite. At back lifting the activity started regularly during stooping to clasp the box and then went on before the lift-off and during the first phase of the lift, whereupon the activity gradually fell to become low when the IAP was high. At the leg lifts the activity rose fairly quickly and reached its peak at the same time as the IAP.

Concerning the back muscles there was a clear difference between back lifting and the two leg lifts as regards the times when the *activity of the erector spinae* started and reached its maximum and when the activity ceased at lowering (I, fig. 11). At leg lifts the activity started generally before lift-off and ran throughout the lifting with a maximum about the middle of the lift. When lowering the erector spinae was usually active until the touch-down. At back lifts the activity usually started after 3-17% of the lifting time and reached its maximum at about the end of the lifting. When lowering the activity generally ceased soon after half the time, somewhat later with heavier weights.

There seemed to be a weak positive correlation between the duration of erector spinae activity and the ability to flex the spine and hips. The coefficients of correlation (r) varied between +0.37 and +0.56 for the different types of lifts with the patients ($p < 0.05$ for lifting 10 kg and 25 kg) and between +0.12 and +0.42 for the different instances with the healthy subjects (NS). This seems to suggest that

the stiffer subjects started activating their erector spinae later during lifting than the more mobile ones, and they also ceased activating their muscles earlier during lowering.

The other mobility test (C7-S1-distance) and the straight leg raising test gave too small ranges to allow any calculations.

As for the ITP there were no differences between back lifting and the two leg lifts. The interindividual variations were considerable, regardless of the technique used. We could not find any common shapes at all of the pressure curves, differing the back lifts from the leg lifts, as was usually seen with the IAP.

3. The low back patients compared to the healthy subjects (study II).

Trunk flexion strength.

The low back patients exhibited reduced trunk flexion strength as compared to the healthy subjects (II, table III). The difference was highly significant ($p < 0.001$). When attempting to test flexion strength three patients reported pain and were excluded.

Trunk extension strength

The two groups showed no difference in trunk extension strength (II, table III). Those reporting pain during the test were excluded also in this case.

Extension/flexion-ratio

The ratio was determined for each subject by dividing the extension strength by the flexion strength. The mean ratio of the low back patients was 1.54 and of the healthy subjects 1.29 (II, table III). The difference was significant ($p = 0.015$).

Intraabdominal pressure during lifting

There was no difference in IAP during lifting regardless of weight or lifting technique (II, fig. 3 a + b). The comparison had to be confined to the back lift and to the ordinary leg lift A, as the leg lift B was not included in the programme for the healthy group.

As a result of our concern to avoid any injury to the patients, only five lifts by three patients were reported to be painful, out of about 200 lifts.

The peak IAP occurred at roughly the same time during the lifting in the two groups.

We may conclude that our group of low back patients produced the same average peak IAP during lifting as the healthy group despite the clear reduction of their trunk flexion strength.

Trunk muscle activity during lifting

As the two groups were examined with different electrodes they could not be compared quantitatively. It should, however, be possible to compare the groups as regards the times of start, peaks and end of activity, taking into consideration the possible effects of different sensitivity.

The maximum activity of the oblique abdominal and the erector spinae muscle occurred, on average, at about the same time during the lifting, whether by healthy subjects or by low back patients. This applied to leg lifts as well as to back lifts.

During leg lifting, the erector spinae was activated during the whole cycle, in both groups. During back lifting, on the other hand, there was a clear difference in the duration of detectable activity (sensitivity 600-1000 $\mu\text{V}/\text{cm}$). The low back patients started activating their erector spinae muscles earlier and, moreover, the activity lasted longer during the lowering (II, fig. 4). The differences are significant for all weights, liftings ($p < 0.05$) as well as lowerings ($p < 0.01$). The times were calculated from the mingograph records with the same method for both groups.

A comparative stiffness as reflected by the distance between fingertips and floor during forward flexion affected the duration of erector spinae activity (see above). The low back patients and the healthy subjects were fairly comparable as regards spinal and hip flexion. The possible interrelationship between the variables was examined, and we can conclude that the effect on the erector spinae activity from stiffness, (see above) could not wholly explain the difference between the patients and the healthy subjects.

4. Effects of abdominal muscles training (studies I and III). This report is confined to the training effects on non-sportsmen, i.e. the healthy subjects and the low back patients, otherwise the results would be biased from the effects of other training. The training of the weightlifters will be commented on when dealing with the causal factors of IAP rise.

a) *Trunk flexion strength*

The strength before and after training was compared in two ways:

1. Measurement of the trunk flexion strength showed an average increase of 26% in the healthy group and of 22% in the patient group ($p < 0.0001$ in both cases).

The maximum EMG activity of the oblique abdominal muscles during the strength test before training was compared with that after training. For the healthy subjects a significantly increased activity was found, on average +42% ($p < 0.01$). In the patients there was no average increase but a positive correlation between increase of strength and increase of activity ($r = 0.55$, $p = 0.014$). Three and four subjects respectively had to be excluded from this comparison due to technical interference or back pain.

2. The load at training may be regarded as an indirect measure of the increase in muscle strength as the external torque and the holding time were increased with the improved capacity of each subject. All the subjects could perform heavier tasks after than before training (I, fig. 6 and III, fig. 3). This was true for both groups, although the patients generally started with minor loads (in agreement with their reduced trunk flexion strength).

b) *Trunk extension strength*

Measurement of the trunk extension strength showed an average increase of 32% ($p < 0.0001$) in the healthy group and of 12% ($p < 0.001$) in the patient group.

The maximum EMG activity of the erector spinae was compared before and after training. Two and six subjects respectively had to be excluded for technical reasons or because of back pain. The remaining healthy subjects showed an average increase of 15% ($p < 0.05$), while the back patients showed no increase after training and no correlation between change in strength and change in activity.

c) *Intraabdominal pressure*

Neither the peak IAP nor the average values during the whole lifting were significantly affected by the training, in any group or at any type of lift.

The average differences were 0.30 kPa in the healthy group and 0.09 kPa in the patients when lifting, and 0.05 kPa in the patients when lowering.

There were, however certain individual differences as regards the effects of training. Thus, four of the healthy subjects and one of the patients exhibited marked increases of IAP after training. Those five subjects showed, however, no significant characteristics which, in retrospect, could be linked to their ability to benefit by training.

Moreover, two patients reported pain during the heaviest lifts after training. One of these increased his IAP by 3-4 kPa and the other one reduced his pressure during lifting by 4-5 kPa.

In contrast to this general lack of effect during lifting, some effect appeared during the strength tests after training. Table IV shows that, beside the great variations between individuals, there was a significant increase of IAP in the patients at both strength tests. A positive correlation was also found between the values of trunk flexion strength and maximum IAP during the same strength tests in the patients (before training $r = 0.61$, $p < 0.05$, after training $r = 0.74$, $p < 0.01$). In the healthy subjects we found

no significant increase of IAP after training. The two groups increased their trunk flexion strength to about the same extent (+22% and +26% respectively). The healthy subjects increased their trunk extension strength by 32% and the patients by 12%.

Tabel IV. Intraabdominal pressure (IAP) during trunk muscle strength tests before and after muscle training. Mean (SD) of the median values of three tests of each subject.

Strength test		Healthy subjects (n = 18)				Low back patients (n = 14)			
		Before	After	Diff		Before	After	Diff	
				kPa	%			kPa	%
Trunk flexion	mean	10.5	12.0	1.5	+14	NS	11.7	16.7	5.3 +45
	SD	6.1	3.9	5.4			4.3	5.0	4.9
Trunk extension	mean	11.3	13.5	2.6	+23	NS	16.0	20.2	4.5 +28
	SD	5.0	7.0	6.1			4.1	6.2	5.7

d) *The oblique abdominal muscles*

The myoelectrical activity of the oblique abdominal muscles decreased after training, in all groups and at practically all types of lifts. This effect of training was very uniform throughout the study, and the difference was significant for the whole material with healthy subjects and for large parts of the lifting times with the patients.

e) *The intrathoracic pressure*

The ITP was not recorded in the healthy group. For the patients there was a clear decrease of ITP after training. The average differences were 1-2 kPa with leg lifts or back lifts of 10, 25, and 40 kg. For the lighter weights, this difference was significant ($p < 0.05$) throughout the liftings and lowerings. For the 40 kg lifts the difference was significant ($p < 0.05$) during about 60% of the lifting times and 50% of the lowering times.

f) *The diaphragm*

The transdiaphragmatic pressure difference (Pdi) was calcu-

lated for the patients but not for the healthy group.

Pdi_{max} during the Mueller manoeuvres was not affected by the training. This should mean that the diaphragm was not strengthened during the abdominal muscle training.

The average Pdi during lifting was, throughout the study, slightly increased after training, by 1.4 kPa on average. This increase could be explained by the average decrease of ITP together with the generally unchanged IAP.

g) *The erector spinae*

The myoelectrical activity of the erector spinae muscle showed no differences after training, in any group or at any type of lift.

Apart from these average results we found in a number of lifts by those few subjects who exhibited a great difference of IAP after training that the erector spinae activity rose or fell inversely to the rise or fall in IAP (e.g. V, fig. 8 a + b).

h) *Lifting time and patterns of activation*

The average lifting times for the different techniques and loads were 1.7-2.0 s. before training with no significant differences between the healthy and the patient groups. The average reduction after training was 10% and 17% respectively.

The average lowering times for the different techniques and loads were, before training, 1.5-1.7 s. for the healthy subjects and 1.9-2.2 s. for the patients. The average time of lowering did not change after training in the healthy subjects but was reduced by 17% in the patients.

The patterns of activation, as reflected by the times of peak IAP and maximum myoelectrical activity in the healthy group and by the shapes of the average curves of pressures and myoelectrical activity in the patient group were quite unaffected by the training, apart from the general reduction of the oblique abdominal muscle activity and the ITP.

This was most clearly seen on the average curves (e.g. III, fig. 6 a + 6 b and 9).

5. The effects of lumbar spinal support and weightlifter's belt (study IV).

The support of syrlon was tested in the patients when lifting 0, 10, and 25 kg and both supports in the weightlifters when lifting 55 kg.

- a) *The intraabdominal pressure rose uniformly throughout all lifts. The increases comprise also the registered periods of 0.5 s. before the lift-off and 0.5 s. after the touch-down and also, when the subjects performed a lifting motion without any load in their hands.*

For the support of syrlon the average increases were 1.0-2.0 kPa, irrespective of the lifting technique and the weight of the burden. For the belt, the average increases were 2.3-3.0 kPa during the whole lifting time. The differences were significant ($p < 0.05$) in the lighter lifts where the absolute values of IAP were lower, but not in the heavier lifts.

- b) *The oblique abdominal muscles, as shown by their myoelectrical activity, were quite unaffected by the two supports, at any type of lift and at any phase of lift.*
- c) *The intra-thoracic pressure did not rise significantly in any instances but there was a tendency towards increased pressures in back lifts with 10 and 25 kg and in the lifts with 55 kg (only leg lifts performed) by 0.5-1.3 kPa on average.*

During the 0.5 s. proceeding or following the lifts there were generally slight increases by 0.3-0.7 kPa on average.

- d) *The diaphragm*

When lifting with the two supports, the transdiaphragmatic pressure difference (Pdi) coincidental with the peak IAP did not change noticeably during back lifts with 10 and 25 kg. On the other hand, there were average increases of 1.7

kPa when lifting the same weights with leg lifting. Leg lifting of 55 kg by the weightlifters increased the Pdi by 1.9 -2.5 kPa, on average. These values could be compared to the average variation of Pdi during quiet breathing in the standing position (0.85 kPa for men according to Gilbert 1981).

e) *The erector spinae muscle*

The myoelectrical activity of the erector spinae increased significantly during the whole lowering at back lift 25 kg with a lumbar support but was otherwise quite unaffected throughout all lifts and lowerings, at all types of lift and with all supports.

f) *Lifting time and patterns of movement*

Lifts with a support tended to run somewhat faster, at least not slower, than those without a support. The tendency was uniform, at all techniques and loads. The mean differences were, however, small, 0.1-0.2 s. out of average times of lifting of 1.6-2.0 s. and of lowering of 1.7-2.2 s.

The electrogoniometer on the subjects' left knee showed that they did not change their way of lifting as regards the knee angle when lifting with a support.

The patterns of activation, as reflected by the shape of the average curves of myoelectrical activity and pressures were, generally, quite unaffected by the use of a support.

6. The effects of respiration

The natural breathing and different kinds of modified respiration during lifting were studied (study V).

a) *The natural breathing during lifting (V, table III).*

In 160 lifts by the patients and the weightlifters we recorded the subjects' natural breathing. After becoming familiar with the apparatus (V, fig. 1) that forced them to breathe through the mouth but gave no noticeable resistance, they were asked to lift as usual.

The subjects held their breaths in 20-45% of the cycles. In the remainder they seemed most commonly to expire when lifting and inspire when lowering. Some started by holding their breaths and changed to breathing in or out during the movements, others began to inspire or expire before lifting or lowering. The weightlifters seemed often to take deeper breaths than the patients.

A positive ITP during lifting was always concomitant with the subject holding his breath.

For both patients and weightlifters who breathed there was no definite correlation between the breathing volumes and the ITP or the IAP.

b) *Breath holding after maximal inspiration (V, fig. 3).*

Maximal inspiration before the start of the lift, followed by breath holding during lifting did not affect the peak IAP or the myoelectrical activities of the oblique abdominal muscles and the erector spinae muscle during 0.3 s. coincidental with the peak.

This was also true for the timing of the maximum of the three mentioned parameters during the lifts.

The ITP was not recorded during moments b, c and e.

c) *Breath holding after maximal expiration (V, fig. 3)*

Maximal expiration before the start of the lift followed by breath holding during lifting did not either affect any of the three parameters significantly. The peak IAP and the myoelectrical activities of the oblique abdominals and the erector spinae remained unchanged both in quantity and in point of time during the lifts, compared to lifts with natural breathing.

d) *Expiration during lifting (V, fig. 4)*

The IAP decreased significantly during 30% of the lifting time with leg lift 25 kg. In all other instances with 10, 25 and 40 kg there was no change at any technique or at any phase of the lifts.

The ITP decreased significantly (3-4 kPa on average) during all lifts with 40 kg. For the lifts with lighter weights there were no significant changes but a tendency towards lower values in some instances.

The myoelectrical activity of the oblique abdominal muscles increased significantly during the last phase of lifting with 25 kg, but otherwise there were no changes.

The myoelectrical activity of the erector spinae was quite unaffected in all instances, at all weights and techniques.

e) *Expiration with facilitation before lifting*

We tested a special technique, suggested by Lewit (1976) to facilitate the abdominal muscles. The subjects started with a maximal inspiration. They then rose on the forefeet, and went down on the soles again at the same time as they, during expiration, bent down to grasp the box. The lift itself was then performed with their natural breathing technique.

This technique increased the average activity of the oblique abdominal muscles significantly with back lifting 25 kg, but

the IAP was quite unaffected. In all other instances there were no change of the three parameters.

We may summarize that none of the tested breathing techniques increased the IAP during lifting. The two modes of expiration increased the activity of the oblique abdominal muscles in some instances, but with no response from the IAP. On the contrary, there was a decreased IAP and ITP in some lifts during expiration.

7. The causal factors of the IAP rise during lifting.

The factors involved in the rise and maintenance of the IAP during lifting were investigated in study V, but some important findings appeared already in studies I-III. Below these results will be summed up for each structure.

a) *The oblique abdominal muscles*

The healthy subjects and the low back patients produced the same IAP during lifting in spite of different trunk flexion strength.

Abdominal muscle training gave a marked increase of trunk flexion strength in healthy subjects as well as in low back patients but no increase of IAP during lifting in either group.

In contrast there was an increased IAP during strength tests after training when the muscles were maximally activated.

In both the healthy and the patient groups, there was no correlation between, on the one hand, the change of activity of the oblique abdominal muscles, and on the other hand, the change in the IAP before and after training. The calculations were made from the peak IAP and the coincidentally recorded activity. We might thus conclude that an increase or decrease of the activity of the oblique abdominal muscles did not generally result in a rise or fall respectively of the IAP. This agrees with the observations from separate lifts in study V (V, fig. 6, 7 and 8). The activity was there shown sometimes to rise simultaneously with the pressure rise, sometimes without any pressure response.

At leg lifting the peaks of activity and of IAP occur roughly at the same time, but at back lifting there is a fairly large discrepancy between the two with the maximum activity around the lift-off and the peak IAP after the middle of the lift.

b) *The diaphragm*

The function of the diaphragm during lifting was reflected by the transdiaphragmatic pressure difference (Pdi).

The strength of the diaphragm was reflected by the Pdi_{max} during the Mueller manoeuvre.

A positive correlation was found between the peak IAP during lifting and Pdi_{max} in the patients but not in the weightlifters (V, table IV) and a strong correlation between the peak IAP during lifting and the coincident Pdi (V, table V). This might imply that the diaphragm is important for the IAP level, but that the weightlifters did not use the capacity of their diaphragm wholly, at least not when lifting boxes of 25 and 40 kg.

The strong correlation between Pdi and IAP could also be shown during the whole lifting in many instances (V, fig. 5 - subject A - 6 b, 7 b, and 8 b).

c) *The intrathoracic pressure*

The ITP was always lower than the IAP and positive only when the subject did not breathe.

In contrast to the fairly comparable outlines of the IAP curves, the ITP curves during lifting followed no recognizable pattern (V, fig. 9). There was no significant change of the average ITP with increased loads and the individual variations were great. No correlation was found between the peak IAP and the simultaneous ITP among the patients but, on the other hand, a significant correlation in the weightlifters in some instances.

d) *The puborectalis muscle*

The three subjects investigated during lifting showed different timings of the puborectalis muscle activity, and different degrees of recruitment, spontaneously as well as on request. It seemed as though the puborectalis muscle could initiate the IAP rise in some individuals provided the dia-

phragm could react or the airways were closed. Thus, one subject was asked to contract his pelvic floor during lifting, resulting in a pressure rise from 7.4 to 18.6 kPa. In other cases it could not be determined whether the puborectalis muscle was activated primarily or secondarily to a stretch reflex elicited by the increased IAP. Anyhow, the best effect of the puborectalis muscle on the IAP seemed to depend on a good co-ordination with, above all, the diaphragm.

GENERAL DISCUSSION

In the separate papers I-V that form parts of this investigation the different aspects of these separate parts have been discussed in detail. The following is a summing up and synthesis of the main points emanating from this work.

The subjects

Our groups of healthy subjects and low back patients were selected to form as homogenous a material as possible as regards ages, heights, weights and exposure to loads both at work and leisure time. Moreover, the low back patients were selected so as to get a group with fairly uniform cases of chronic illness, in need of improved stabilization and unloading of the lumbar spine.

The weightlifters were selected for their skill, as we wanted to study their technique and the effects of different measures in such cases.

In some respects, for instance trunk muscle strength, our results should be confined to the groups studied. In other respects, for instance the mutual relationship between trunk muscle strength and IAP, the mechanisms responsible for building up and maintaining IAP, the effects of respiration and training, we suggest that the results are applicable also to other individuals.

The great interindividual variations as regards the muscular responses to load and the IAP make it, however, necessary to be very careful when drawing conclusions from experiments with small groups. The same applies also to assessments of spinal stress from IAP recordings.

The methods

Assessment of trunk flexion strength.

Considering that the motion axis is located about the intervertebral disc L3-4, we concluded that the rectus abdominis, the external and internal abdominal muscles had to overcome the extending moments from the erector spinae and the IAP and that the test measured the net effect, provided that the pelvis and the lower extremities were kept immobile by the hip flexors and extensors and the other leg muscles. The psoas muscle accounts for a small portion of the bending moment (Alston 1966) or none (Farfan 1973). The transversus abdominis can exert no bending moment because of the direction of its fibres.

As the oblique abdominal muscles comprise about 60% of the anterior abdominal muscles acting in the longitudinal direction (Morris et al 1961) we may assume that the oblique abdominal muscles account for a considerable part of the flexion strength, and consequently also for a great share of the loss of strength among the patients, and of the gain of strength after training in both groups. This last assumption is supported by the finding that the maximum myoelectrical activity of the oblique abdominal muscles generally increased with the strength.

Assessment of trunk extension strength

Considering the motion axis to be located ventrally to the L1-2 segment the erector spinae muscle as prime mover had to overcome the flexing moment of a certain amount of the oblique abdominal muscles perhaps with some help from an extending moment of the increased IAP. During the test we found a considerable activity of the oblique abdominal muscles - in agreement with Carlsöö (1980) - both in healthy subjects and in patients. Carlsöö (1980) also showed that the rectus abdominis, at least in healthy subjects, was only occasionally and then only slightly activated during the test.

The pressure recording system

The pressure recording system was calibrated statically and dynamically, and it was also tested in a model, in the oesophagus

and during X-ray with satisfactory results as to technical properties. Our peak levels are fairly consistent with those of previous studies with similar lifts but other devices such as balloon-catheter (Morris et al 1961), radio pill (Kumar 1980), and intragastric transducer (Fairbank et al 1980).

Electromyographic recording

We chose surface electrodes to record the myoelectrical activity of the oblique abdominal muscles and the erector spinae, as they offer the best reproducibility at repeated recordings (Komi and Buskirk 1970, Ward 1978).

The electrodes at umbilical level and above the ventral iliac spine recorded mainly the external oblique muscle as it was closest to the electrodes, but some activity from the internal oblique muscle was certainly also picked up. It would have been interesting to record the activity of the transverse abdominal muscle, but that would require intramuscular electrodes with more risks and less reproducibility.

The electrodes over the most prominent part of the erector spinae muscle at the L2-3 level picked up the myoelectrical activity from the iliocostalis lumborum, the longissimus thoracis and, more or less, the multifidi (Jonsson 1970). These muscles are known to be activated simultaneously during flexion-extension (Morris et al 1962, Panly 1966) during standing with a load in front of the body (Jonsson 1970) or during standing in a flexed posture (Jonsson 1974).

We wanted to examine the myoelectrical activity of the pelvic floor during lifting and chose the most prominent part of the levator ani, the puborectalis muscle, assuming that the whole muscle of the pelvic floor, sometimes called "the pelvic diaphragm" works as an entity during lifting.

For the puborectalis muscle we used bipolar fine-wire electrodes. They were placed outside but close to the muscle with an interelectrode distance of about 1 cm. This position was cho-

sen to avoid deformation and fracture of the electrodes which might occur with an intramuscular location (Jonsson 1970). In addition, the electrodes were supposed to pick up myoelectrical activity from a greater part of the muscle.

Leg lift B was the only asymmetrical lift. In a pilot study we could find no significant differences between recordings from the left and right side of the trunk during leg lift B. In addition we aimed at making the back lifts and the ordinary leg lifts (leg lift A in study III) as symmetric as possible, including symmetric loading of the box, to avoid variable lateral flexion and rotation. We may, thus, conclude that there was no asymmetry which could have any influence on the results of this study.

When recording myoelectrical activity under a lumbar support we have to consider that the pressure from the support might reduce the distance between the skin and the active muscle and thus increase the amplitude of the myoelectrical activity. The overall almost identical average curves with and without a support seemed, however, to indicate that there was no important change of recording due to the supports.

The subjects were - throughout the study - allowed to rest between the lifts, thus excluding any risk of muscular fatigue.

The training programme

There are several studies of different modes of abdominal muscle training (e.g. Walters-Partridge 1957, Flint 1965, Flint-Gudgell 1965, Godfrey et al 1977, Halpern-Bleck 1979, Ekholm et al 1979, Ricci et al 1981) but, so far only one study of the effects of training on the IAP (Legg 1981), and no study on the myoelectrical response to the training. In addition all the above examinations were performed with healthy subjects.

From the present studies we may conclude that all our subjects, beside the rectus abdominal muscle, trained their oblique abdominal muscles with one of the most efficient isometric training

methods available.

The training period was five weeks which should be sufficient for evaluation of the benefit of training (Hislop 1963). In addition, the training was intense, and supervised, and we increased the external torque and holding time with the improved capacity of each subject.

The results

Back lifting versus leg lifting

Considering in the first place the two leg lifts no comparative study has been published until now. The somewhat shorter lever of the box with leg lift B did not significantly affect the muscular responses or the IAP.

Secondly, as regards, back lifts versus leg lifts, this is an old subject of discussion (e.g. Davis-Troup 1964, Anderson et al 1976, Carlsöö 1980). The present study also affords some points to be discussed. While the back muscles were active during the whole lifting cycle in leg lifting, there was no detectable activity during the beginning of the lifting and the end of the lowering. It was found that this pattern of activation was correlated to the mobility of the spine and hips (distance fingertips to floor in forward bending). The stiffer the subject, the later the activity started during lifting and the earlier it ceased during lowering. The so called flexion-relaxation is well-known since Floyd-Silver (1951). Jonsson (1970) states this to be due to the interspinosus and supraspinosus ligaments being tightened and taking over the load from the erector spinae muscle. Carlsöö (1975) supposes the variation between individuals to be related to elasticity and mobility. Our finding, in both the healthy and the patient group, agrees with the statements of Jonsson and Carlsöö, but needs further studies on a larger material.

There was a clear difference between the leg lifts and the back

lifts as regards the relative timing of oblique abdominal muscle activity and IAP. During the leg lifts they were usually well synchronized with coincident peaks, whereas during the back lifts the muscular activity was maximal roughly at the lift-off and rather low when the IAP reached its peak. This implies an imbalance between the tension of the abdominal wall and the pressure from inside, which might have some importance for the development of inguinal hernia, especially if the same muscular pattern applies to all the oblique and transverse abdominal muscles. Some hernias have been related to lifting (Davis 1959) sports activity (Gullmo 1980), and increased intraabdominal pressure (Frankson 1981).

Morris et al (1961) found higher IAP in leg lifting compared to back lifting, and Eie-Wehn (1962) the reverse. Anderson et al (1976) found no significant difference between the two techniques but a tendency towards higher values in back lifting. The results of the two groups of subjects are different. In the healthy subjects leg lifting produced higher values than back lifting, whereas there was no difference in the patients. The explanation is obscure and further studies are needed to analyse this phenomenon.

The low back patients compared to the healthy subjects.

The main conclusion was that the low back patients and the healthy subjects produced the same IAP during lifting despite a clear difference in abdominal muscle strength. Fairbank et al (1980) did not assess the trunk muscle strength but reported the same results as regards the IAP during painless lifts of 5 and 10 kg.

Fairbank et al (1980) found higher pressure during painful lifts. In our series, however, only five lifts were reported painful with very inconsistent values, and therefore no comments can be made on the effect of pain on IAP.

Pain may be a confounding factor in any strength test, or even fear of pain. The recordings of painful strength tests were,

therefore, excluded from the calculations. The remaining 17 patients, like the healthy group, reported no pain during the tests. In fact, in their experience the risk of pain was greater at extension test than at flexion test. It thus seems unlikely that the difference in strength should be due to pain during the tests.

The duration of erector spinae activity during back lifting showed interesting differences. We have already discussed the effect of stiffness (see above). A significant difference was also demonstrated between the patients and the healthy subjects. The patients kept up the activity of their erector spinae longer than the healthy men, especially during lowering (II, fig 4). This difference could not be wholly explained by differences in stiffness. Floyd and Silver (1955) also found a difference between healthy subjects and out-patients with back-ache as regards back muscle activity during trunk flexion. They noted that the patients when recording changed to the pattern of the healthy subjects and concluded that they activated the erector spinae to protect injured and painful ligaments. If this is the case, our subjects with low back pain seemed to have maintained this pattern of extended erector spinae activity, although they were not in pain at the time of examination.

Effects of abdominal muscle training

The muscular and pressure response to the training was very uniform throughout the study. The maximum abdominal muscle strength increased, and the recruitment of motor units in the oblique abdominal muscles improved in maximum strength tests but decreased in liftings. Moreover, the IAP was generally quite unaffected by the training as was the activity of the erector spinae muscle.

Apparently the curl up training did not generally shake the pattern of activation used in lifting. The abdominal muscle cells had become stronger, and then fewer motor units had to be elicited to perform a given muscular work. But this change in the abdominal muscles did not affect the building up of IAP

or the recruitment of motor units in the erector spinae muscle.

Legg (1981) trained the abdominal muscles in healthy subjects by dynamic sit-ups. There was no effect of this training on the IAP in lifting according to his results. This is consistent with our results despite the difference in training methods.

The diaphragm was not strengthened by the training, according to the Pdi_{max} during the Mueller manoeuvre. The Pdi during lifting, however, increased 1.4 kPa, on average, indicating that the diaphragm was more activated, stretched or more curved in the lifts after training (or a combination of these factors) according to the Laplace law.

We cannot determine why the ITP during lifting decreased after training. One explanation could be that the volume of the thorax increased with an increased activity of the diaphragm. Another, that those subjects who lifted with a closed airway before training opened the glottis while lifting after the training.

The effects of lumbar spinal support and weightlifter's belt.

Morris et al (1961) studied the effects of a non-elastic lumbosacral corset on the IAP and the trunk muscle activity. The corset had an inflatable bladder covering the abdominal wall. The bladder was inflated "to the limit of comfort" at rest and during "static loading". Grews and Deane (1982) studied the effects on the IAP of five different lumbar spinal supports at rest, in different postures and during lifting of 15 kg. Both elastic and non-elastic corsets and braces were used.

were used.

The two non-elastic supports used in the present study had principally the same effects on IAP. The IAP was generally increased by 1.0-1.5 kPa, both in patients and weightlifters, in unloaded situations, such as before lift-off and after touch-down. The pressure increase was the same when they performed lifting motions without a load. These results agree with those of Morris

et al and Grew and Deane, irrespective of the different types of supports.

When lifting 10, 25, or 55 kg about half of our patients and weightlifters showed a slight further increase by 0.5-1.5 kPa on an average, irrespective of lifting technique, weight, or group of subjects. In these subjects the pressure was evenly raised over the whole cycle.

Grew and Deane reported a slight but not significant increase of IAP when lifting with a support compared to lifting without a support.

The findings indicate that any lumbar spinal support may increase the IAP at rest and in unloaded postures. When loads are lifted, the IAP may increase further. There is however no definite correlation between the weight of the load and the further IAP increase.

The myoelectrical activity of the oblique abdominal muscles and of the erector spinae muscle was, on the whole, quite unaffected by short-time application of the two supports, at all types of lifts, and in both groups. It thus seems clear that the support and belt used in this study did not reduce the trunk muscle activity in any lifting motion. The effects of spinal supports on trunk muscle activity during lifting has not been studied before.

On the other hand, inflatable corsets had no influence on the IAP in static loading, but markedly decreased the myoelectrical activity of the oblique abdominal muscles, as reported by Morris et al (1961). Further studies are needed to analyse the long term effect of spinal supports on trunk muscle recruitment. The transdiaphragmatic pressure difference increased simultaneously with the IAP rise in the leg lifts but not in the back lifts, irrespective of the weights. This indicates that the diaphragm could respond more easily to the increased IAP from the support or belt in the leg lift posture than in the stooped posture used in back lifting. This phenomenon could also explain that during

back lifting, some of the IAP was also transmitted to the thorax thus increasing the intrathoracic pressure.

The effects of respiration.

Trials with four different modes of breathing before and during the lifts showed no influence on the intraabdominal pressure during lifting. The intrathoracic pressure decreased significantly, when the subjects lifted heavier weights (40 kg) during expiration. This increased the demands on the diaphragm.

The oblique abdominal muscles were more activated in some lifts during expiration, with or without facilitation. This increased muscle activity during the end of expiration did not influence the IAP.

Breathing techniques have been stressed in some instruction programmes concerning lifting techniques. The point is, however, not the phase of respiration but rather whether the airways are open or closed. The closing of glottis enables us to build up a positive intrathoracic pressure (ITP) which will support the diaphragm from above and thus diminish the demands on that muscle. Breath holding with an open airway is not sufficient. The ITP will not exceed - 0.5 kPa as long as the pressure within the alveols is equal to the open air pressure.

Davis (1964) suggested that females when stopping to lift more often contract the diaphragm against a high abdominal pressure while keeping the glottis open, and that males more often close the glottis and raise both the ITP and the IAP. The present study, including only males, did not show a uniform picture as for the ITP but, on the contrary, a great variation.

The causal factors of the IAP rise during lifting

The abdominal cavity contains mainly fluid and semisolid material. Its pressure characteristics has been examined by Rushmer (1946), Nordenfelt (1959), Bjerle (1974) and others. Thus, the abdomen with its contents resembles an incompressible ball except for the small amounts of gas that may occur in the stomach

and the colon.

From a mechanical point of view, it seems clear, that every muscle lining the "ball" can initiate a rise in pressure provided the other parts of the wall co-contract or at least passively withstand the pressure from the inside. There is always a "force balance" (Broberg 1981) between the IAP and the tensile forces of the wall.

The ideal muscles for pressurization are those which can contract without giving a bending moment on the lumbar spine, i.e. the pelvic floor muscle, the transverse abdominal and the diaphragm.

The mechanism responsible for the IAP rise during lifting has been discussed in several papers, though no unequivocally clarified (e.g. Bartelink 1957, Morris et al 1961, Grillner 1978). Kumar (1971) and Kumar-Davis (1973) studied the afferent part of the hypothetical reflex and suggested that it might be elicited from the erector spinae "if a reflex exists". The oblique abdominal muscles have been considered essential for the efferent part of this hypothetical reflex. The diaphragm and the pelvic floor have not been studied previously in this context.

During lifting, the maximum activity of *the oblique abdominal muscles* generally increased with increased external load. Considering the whole lifting cycle there was no clear connection between the average myoelectrical activity of the oblique abdominal muscles and the weight of the box lifted. During lowering there was except for the highest loads, no clear increase of activity with increasing external load.

Summing up all our data it seems clear that the oblique abdominal muscles are of no decisive importance for the building up of IAP. This agrees with Kumar's conclusion (1971): "the intraabdominal pressure may obviously be affected more by contraction of other abdominal muscles than the external obliques." The reported

strong correlation between the oblique abdominal muscle activity and IAP (Kumar 1971, 1980) may thus be coincidental rather than causal.

The myoelectrical activity of the *transverse abdominal muscle* has not been recorded, so far, due to technical problems. It is, however, worth mentioning that the transverse abdominal muscle anatomically belongs to the same group as the diaphragm and the transverse thoracic muscle, (Bartelink 1957). Unlike the other abdominal muscles, it serves no other purpose than compressing the abdominal "ball". Thus, recording of its activity during lifting could be of interest.

The *rectus abdominis muscle* was not included in this study as it has previously been shown that it is rather inactive during lifting of light or moderate weights (Bartelink 1957, Morris et al 1961, Ekholm et al 1982).

The evaluation of the role of the diaphragm in the building up and maintenance of the IAP during lifting was based on the transdiaphragmatic pressure difference data. The background to this was elaborated on pages 34-46 and 53. In addition to that evidence Grassino et al (1978) have described a curvilinear relationship between the Pdi and the myoelectrical activity of the diaphragm in static contraction. Sears et al 1968 found an almost linear relationship between the Pdi and myoelectrical activity of the diaphragm during the Mueller manoeuvre. Thus there seems to be sufficient evidence to justify the conclusion that the data of Pdi give a proper estimation of the diaphragmatic activity during lifting. Our results show that the diaphragm is activated during lifting and the activity increases with increasing load. In addition the IAP level seems to depend on the activation of the diaphragm during lifting and, partly, to the strength of the diaphragm, as assessed from the Mueller manoeuvre in the patient group.

The *puborectalis muscle* has previously been shown to be active during respiratory movements, during phonation and during cough-

hing (Taverner-Smith 1959, Thre 1974). From our study we can add that the puborectalis muscle seems to take part also in lifting. The puborectalis muscle can probably also initiate an IAP rise in some cases, provided the diaphragm co-contracts or the subject closes his glottis.

In summary, the building up of IAP is a matter of co-ordination between the muscles involved. The diaphragm is the most important muscle for the IAP level, but it could be relieved by closing the glottis.

It was also shown from many graphs that preprogramming was not unusual in those subjects who got a high IAP during lifting. This might be the key to an optimal utilization of the IAP during lifting.

GENERAL SUMMARY

Low back pain is a major medical and socio-economic problem. To arrive at methods meeting the great need for efficient prevention we must have a detailed concept on the trunk reaction to load. The aim of this investigation was to analyse the responses of the intraabdominal pressure and trunk muscle activity to loads during lifting and to evaluate different measures taken to affect the responses.

Twenty male healthy subjects, twenty subjects with chronic low back pain of 2-18 years duration and ten skilled weightlifters took part in the investigation.

Each subject performed a series of standardized lifts with and without modification. The following parameters were registered simultaneously:

- 1) intraabdominal pressure (IAP)
- 2) myoelectrical activity of the oblique abdominal muscles, the erector spinae muscle and - in certain subjects - the lateral vastus muscle and puborectalis muscle
- 3) intrathoracic pressure (ITP) in part of the material
- 4) respiration in part of the material.

The lifts were recorded by video or film camera.

Observations and results:

1. The common characteristics of lifting were described as regards the IAP and the ITP, and the myoelectrical activity of the oblique abdominal, the erector spinae, and the puborectalis muscles. The function of the diaphragm was evaluated by the transdiaphragmatic pressure difference.
2. The differences between back lifting and leg lifting were studied. The intraabdominal pressure was significantly higher

in leg lifts than in back lifts in the healthy subjects but there was no difference in the patient group. The timing of activation of the oblique abdominal and the erector spinae muscles differed between leg lifts and back lifts in both groups. There was a delay of peak IAP relative to the oblique abdominal activity in back lifting which may be important as regards the development of hernia.

3. The low back patients were shown to have a reduced abdominal muscle strength compared to the healthy subjects. The intra-abdominal pressures during lifting were, however, equal in the two groups.

The duration of erector spinae activity was significantly longer in the patient group than in the healthy group.

4. Isometric abdominal muscle training increased the abdominal muscle strength significantly but did not increase muscle recruitment during lifting. On the contrary, the activity of the oblique abdominal muscles was generally decreased. The average IAP and the average erector spinae activity were not affected. These results apply to both healthy subjects and low back patients.
5. Weightlifter's belts and lumbar spinal supports were tested in patients and weightlifters. The two supports gave principally the same effects. IAP increased by 1-1.5 kPa, on average, in unloaded postures. There was in half of the lifts a slight further increase, unrelated to the weight of the burden. The myoelectrical activity of the oblique abdominal and erector spinae muscles were quite unaffected in this short-time study.
6. Natural breathing was recorded and four different breathing techniques were tested. None of the applied techniques of respiration increased the IAP significantly.
7. The factors responsible for the building up and maintenance

of the IAP rise during lifting were analysed. Lifting was found to be a matter of coordination rather than strength of the muscles around the abdominal cavity. The diaphragm is the most important muscle for the IAP level. An increased intrathoracic pressure could, however, support and relieve the diaphragm from above, but this implies that the airways are closed.

CONCLUSIONS AND PRACTICAL IMPLICATIONS

Basic knowledge is essential for prevention as well as for treatment. It is necessary to study the process of work such as lifting to find out what movements can be altered as they may have a detrimental effect on the worker.

Dynamics are more than acceleration and moments of inertia. In biomechanics it is also important to consider the delicate and variable patterns of activation during motion, especially if we want to interfere through prevention or treatment. This study has shown that lifting can be performed in various ways "under the skin" even if we cannot observe any differences from outside. A certain "standardized" lift can be done differently by different people, and it can also be done differently by the same subject after intervention. Such variation cannot be explained by changes of acceleration, levers or body position.

Lifting cannot be studied by holding weights in static postures, just as we cannot study walking by evaluating standing. The patterns of activation are quite different, which can be seen both from electromyography and from pressure recordings.

Measurement of IAP has been used to define limits of acceptable loading in work situations. It must be borne in mind, however, that there is a considerable variation of pressure response to external load in different individuals.

Isometric training of the abdominal muscles did not generally affect the interplay between the IAP and the erector spinae. The main effect noticed was that the strengthened oblique abdominal muscles could reduce its number of engaged motor units, as reflected by the reduced myoelectrical activity during lifting. On the other hand, during maximal effort of all the engaged muscles the IAP was significantly increased after training. A trunk muscle strength test - like a Valsalva manoeuvre - is a matter of maximal activation where an increase of

strength gives a definite effect on the IAP, while lifting for the muscles around the abdominal cavity is a matter not so much of strength as of co-ordination, which was not influenced by this type of training.

This study has thus confirmed that the effect of muscular training is very specific also for the abdominal muscles. Training for strength is, of course, not useless but only indicated when increased strength is wanted. As for the anterior abdominal muscles this is the case in forceful trunk flexion or attempted flexion such as pushing, and when a maximal Valsalva manoeuvre is needed, as in bronchitis with mucus or in constipation.

In other situations, such as standing or sitting for a long time, the trunk muscles probably need a good endurance and that should demand another type of training.

Thirdly, lifting, carrying and similar tasks seem to demand, above all, a good co-ordination between the trunk muscles, and, in addition, a strong erector spinae muscle.

Those few subjects, mostly weightlifters, who benefited by the training with an increased IAP during lifting, were shown to change their patterns of activation. The oblique abdominal muscles and the diaphragm were better co-ordinated after training and they also activated their muscles earlier during the lifts, even before the lift-off. Such a pre-programming may be the key to an improved use of the IAP for stabilization and unloading, also when considering that the external load during lifting is probably often greatest at the lift-off.

In summary, if we want to make use of the stabilizing and unloading effect of the intraabdominal pressure, preventive training should be directed more towards skill of lifting than towards muscle strength.

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Intraabdominal Pressure and Trunk Muscle Activity during Lifting – Effect of Abdominal Muscle Training in Healthy Subjects.

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INTRODUCTION

The intra-abdominal pressure (IAP) and its relation to the load on the lumbar spine when lifting have been made the object of several studies (e.g. 2, 4, 8, 12, 13, 15, 19, 20, 22). A connection was then found between an increase of the external load and an elevation on the IAP. Using biomechanical calculations, several authors (e.g. 4, 6, 9, 12, 13, 22) have suggested that an increase of the IAP should relieve the load on the lumbar spine in certain situations, e.g. when lifting.

It therefore seemed reasonable to advocate isometric training of the abdominal muscles as preventive measure against low back pain, in the hope that the increase in strength of the muscles should result in an increase of the IAP when lifting (23, 24). It has not, however, to our knowledge, been shown that an increase of the strength of the abdominal muscles results in more activity of those muscles when lifting, nor that more activity of the abdominal muscles necessarily yields an increase of the IAP at different kinds of lifting. Nor has any preventive effect been shown from this type of training of the abdominal muscles, such as a decrease in the recurrence of low back pain.

The aim of this study was therefore to investigate the effects of isometric training on the strength of the abdominal muscles and on the activity of these muscles and the IAP when lifting. To start with, healthy subjects were chosen, so that normal physiological conditions could be studied.

MATERIAL

Twenty male volunteers were chosen among employees in the building trade. The subjects were taken from the same occupational group (electricians), and they were all comparatively physically inactive in their leisure time. The reasons for

this principle of selection were, first that their exposure to loads, both at work and leisure time, should be as similar as possible and secondly, that with such subjects the greatest possible effect of muscular training could be expected. Their age was 23-33 years (mean 28), height 171-187 cm (mean 180) and all had a normal body weight (mean 75 kg).

None of the subjects had had or was suffering from back complaints. An ordinary routine examination of back, hips and other joints, and other routine tests were quite normal in all cases. None had a suspected inguinal hernia. They were all instructed in lifting technique as regards leg lifting before the examination, so that they all had roughly the same information. Except for one person, none of them had had any previous instruction in lifting technique.

METHODS

Assessment of trunk flexion strength

1. Scoring according to the Janda scale 1-5 (16) was carried out, without fixation of the feet. The subject lay on his back, the hip joints flexed about 60 degrees, the soles of the feet pressed against the floor and the arms either along the body, stretched forward, abducted with the hands folded behind the neck, or stretched behind the neck. During the test, the trunk was slowly curled up until the apex of the scapula lifted from the floor or the pelvis started to rotate ventrally.

2. Measurement of the strength of the trunk flexors was carried out in the upright position with the back against wallbars (Fig 1). The strap of the recording instrument was placed across the chest and upper arms at the level of the attachment of the deltoid muscles. The tension in the strap was recorded by means of a Salter balance. The recording system was calibrated daily. The position of the feet in relation to the wallbars was measured. The subjects were told to make a trunk flexion and not a hip flexion and the position and minute movements of the body during the test were carefully regis-

tered to make the conditions for each subject before and after training quite comparable. Recordings were made of three successive maximal contractions during at least 3 sec. The estimates were then made from the median values.

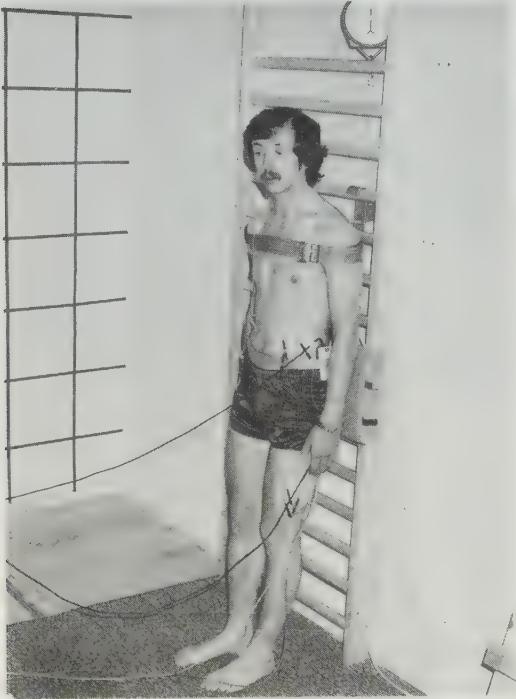


Fig. 1. Measuring the trunk flexion strength.

To determine which muscles are responsible for the trunk flexion we had to calculate the bilateral motion axis during our test procedure. The minute movement during the strength test was analyzed according to Reuleaux (28). The thoracic cage regarded mechanically as a rigid body, was supplied with three pointers attached to the skin over the sternum and the subject was asked to perform the test by flexing the trunk forward against the strap. The test was filmed from the side and the motion of the pointers calculated from the film and accordingly the bilateral motion axis. We could then find that during our test the axis lies about the intervertebral disc L3-L4. If the subject instead of flexing the trunk made a hip flexion with straight back his motion axis was located about the hip joint.

Assesment of trunk extension strength.

Determination of the strength of the trunk extensors was performed with the same methods, except that the subject faced the wall-bars with the strap placed across the dorsal part of the chest and the upper arms at the same level as before (Fig. 2).

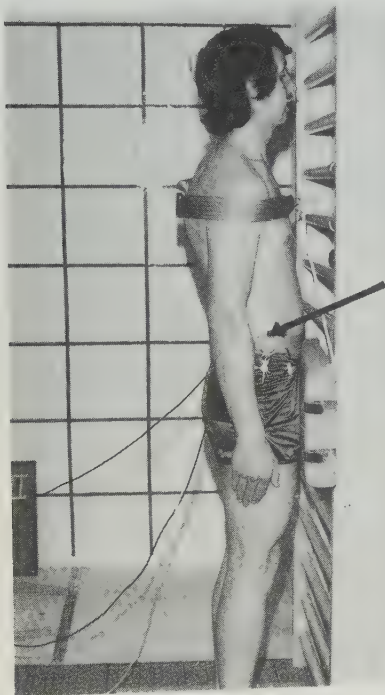


Fig. 2. Measuring the trunk extension strength. Arrow shows IAP transducer.

Electromyographic recordings.

Records were made with pairs of surface electrodes (disposable electrodes 45037 4EH019 Siemens-Elema) and Mingograf 82 (Siemens-Elema). The interelectrode distance was 3 cm. The pairs of electrodes were placed - all on the left side - over the erector spinae at the level of the spinous processes L2-L3, over the lateral vastus muscle with the lower electrode 15 cm above the lateral joint interval, and over the oblique abdominal muscles at umbilical level and above the ventral iliac spine. The direction of the electrodes was parallel to the

direction of the muscle fibres. The lateral vastus muscle was chosen to make it possible to control the activity of the knee extensors during lifting. As regards the abdominal muscles, a pre-amplifier was used with a tenfold amplification, otherwise the signals went directly to the universal amplifier Siemens 854. The myoelectrical activity was recorded both as raw EMG and as integrated EMG. The integration was done with Siemens Integrator EMT 43B over a preset period throughout this study 0,3 s. When measuring trunk muscle strength, the calculations of integrated values of the maximum EMG activity were made at maximum voluntary contraction.

Recordings of intra-abdominal (intragastric) pressure

The recordings were made with an open polyethylene catheter filled with isotonic saline and without balloon. The subjects were not allowed to eat during the hours before the examination. After nose and pharynx had been sprayed with a local anesthetic (Lidokain), three thin polyethylene catheters (Portex PP100 with an internal diameter of 0,86 mm) were introduced through the nose to the upper part of the stomach. By watching the way the pressure changed with the breathing, it was possible to decide when the tip of the catheter had passed the diaphragm and was resting in the stomach. At the first examination the distance between the tip of the catheter and the nostril was noted so that, at the examination after training, the catheter could be placed in the same position. The three catheters were fused at their distal ends, two containing air and intended only as guides, whereas the third was open at the lower end and filled with isotonic saline. By means of a three way stopcock which made it possible to flush the catheter between recordings, it was connected to a pressure transducer (Siemens 746/5), which was placed at the level of the iliac crest (Fig. 2). The variations of pressure were read by means of an electromanometer (Siemens 863) and were then recorded synchronously with the EMG on the mingograph.

In pilot tests before the examination, it was found that the pressure recordings yielded identical values at repeated,

equally large increases of pressure, that the increase of pressure was recorded without any marked time lag (increase of pressure from 0-11,2 kPa in 0,01 sec. with the length of catheter used) and, also, that exactly the same value was obtained whether the point of the catheter rested in fluid or in air in a stomachlike plastic container. Using X-ray it could be shown in one subject that the tip of the catheter remained at same level in spite of repeated kneeling, bending over and lifting, and this could also be discovered by comparing the values of pressure in the upright position, in the stooping position with straight knees, and in the kneeling position before, during and after each test series. From the X-ray we have calculated the source of error due to the external location of the transducer and corrected the pressure values accordingly.

The examination procedure.

1. *Recordings before and after training of the abdominal muscles.* Before and after isometric training of the abdominal muscles, the subjects were put through a standardized test programme where the strength of the trunk flexors and extensors was recorded and a series of lifts was carried out.

Lifts were done with 10, 25 and 40 kg, in all cases with leg lifting as well as back lifting. By leg lifting is meant lifts with bent knees and the back as straight as possible. Back lift was used of lifting with straight knees and bent back. Each type of lift was done twice and all calculations were made from the mean value of the two lifts. Every subject also had to go through several lifting motions without any weight to control the effect of the movements by itself on the IAP. The subjects were allowed to rest between lifts.

Every subject could choose the lifting speed and breathing technique that seemed natural to him, but otherwise the lifts were carefully standardized to facilitate comparisons before and after training. The subject stood in a fixed position relative to the load and a physiotherapist gave instructions

about the lifting technique to be used.

In all lifts, a specially made box was used (Fig. 3). On the box there was an accelerometer by means of which we recorded the beginning and the end of lifting and lowering. The lifts were performed from floor level to the upright position with the load on extended hanging arms in front of the body. All lifts were completely symmetric.

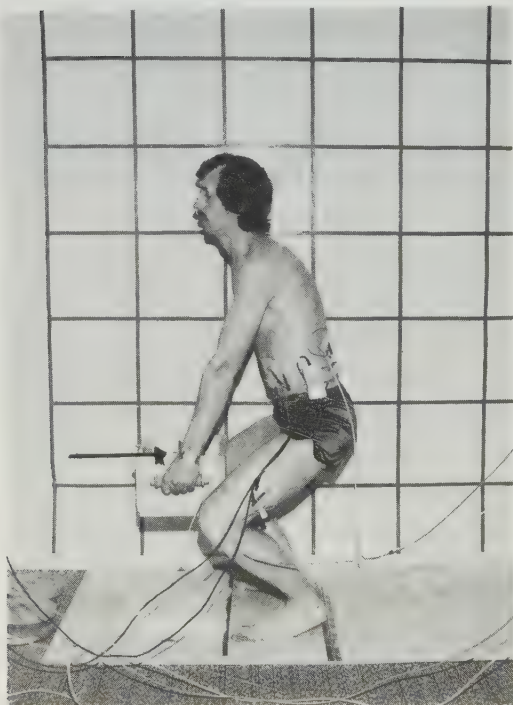


Fig. 3. Example of leg lifting. EMG electrodes over the left oblique abdominal muscles (with preamplifier), the left erector spinae muscle, and the left lateral vastus muscle. The box contains the weights and an accelerometer is attached to the box (see arrow).

The order of lifts was changed between subjects. Each subject did, however, perform the lifts in the same order before and after training.

Fig. 3 shows an example of leg lifting. Figs. 4 and 5 show the recordings of back lifting 40 kg and leg lifting 40 kg.

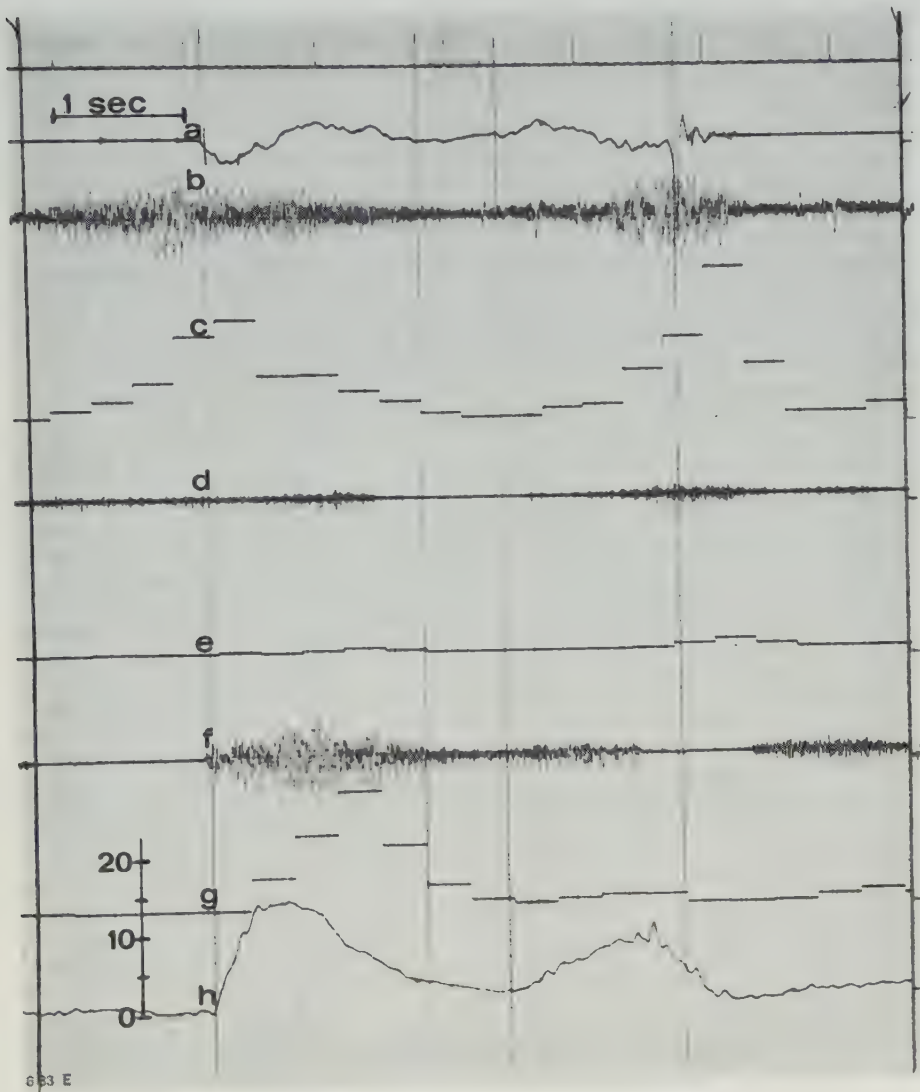


Fig. 4. Recording of back lift, 40 kg. (a) Accelerometer. (b) Left oblique abdominal muscle - raw EMG. (c) Left oblique abdominal muscle - integrated EMG. (d) Left lateral vastus muscle - raw EMG. (e) Left lateral vastus muscle - integrated EMG. (f) Left erector spinae muscle - raw EMG. (h) Intraabdominal pressure.

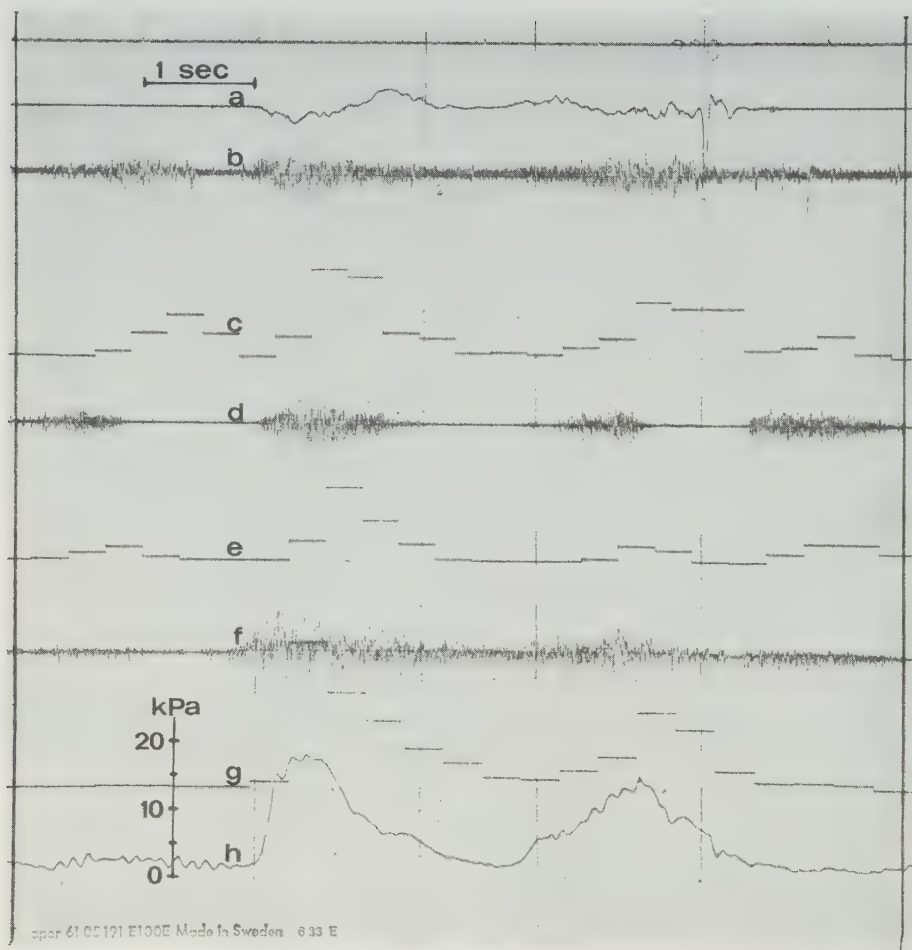


Fig. 5. Recording of leg lift, 40 kg. For explanation cf. Fig. 4.

2. *Isometric training of the abdominal muscles.* Isometric training of the abdominal muscles was performed for 5 weeks. During that time, the subjects were not allowed to do physical exercises or any physical training other than that prescribed. We wanted to achieve the most intense and efficient isometric training possible of the abdominal muscles, and all subjects were very interested in following directions and doing their best. Everyone had detailed personal instruction in the standardized technique to be followed and was checked twice a week throughout the training period. The initial position was supine, with hips and knees flexed, the heels supported, and with active plantar flexion of the feet. The back was pressed against the floor and the gluteal muscles were actively contracted. The training procedure was as follows: the subject breathed out and held his breath, after which the upper part of the body was curled up until the subject experienced a maximal effort, though without changing the position of the pelvis. This posture was held for a pre-set time. Each exercise was performed twice daily, with 10 curl ups on each occasion. The test subjects kept records of the daily training. The load and holding time were raised successively by the physiotherapists according to the individual increase of muscular strength, both by extending the period of holding by 15 seconds and increasing the external torque by varying the position of the arms (Fig. 6).

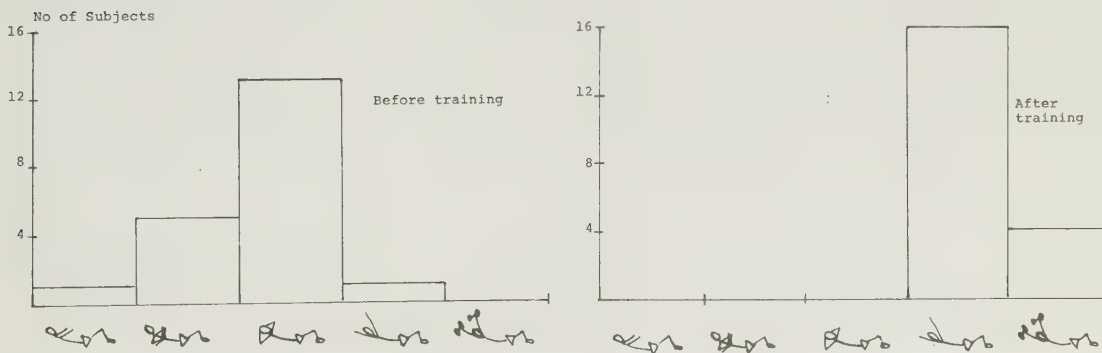


Fig. 6. The external torque could be successively increased during training.

STATISTICAL METHODS

The design of the study was chosen to get a matching situation where each subject could act as his own control in comparisons. This approach was regarded as essential considering the variables studied.

Each lift was performed twice and the calculations were based on the mean value of the two lifts.

The strength of the covariance was determined by Pearson's correlation coefficient, r . The analysis of significance was carried out according to Student's t -test.

RESULTS

Trunk flexion strength

The muscle strength before and after training was compared in three ways:

1. *Score according to a scale 1-5.* Before training, 16 of the 20 subjects reached the highets value and the remaining four subjects were graded 4. After training, all had strength 5.
2. *The load at training* is an indirect measure of the increase in muscle strength, as the external torque and the holding time were increased successively at the same rate as the capacity of each subject improved. Fig. 6 shows that after training, all subjects managed the heavy exercises which only one person could perform before training.
3. *Measurement of strength* before and after training. Table I shows that all subjects except two, exhibited higher values at the second recording, after training. One of those was ill during the week before the second recording. The average increase from 490 to 616 N, corresponding to 26%, was highly significant (p 0,0001).

Table I. Trunk muscle strength before and after training.
Median values of three recordings with Salter balance (N).

Subject	Trunk flexors			Trunk extensors		
	Before	After	Diff	Before	After	Diff
1	520	640	+120	750	780	+ 30
2	420	550	+130	390	580	+190
3	420	610	+190	630	840	+210
4	490	650	+160	360	510	+150
5	430	800	+370	520	770	+250
6	420	590	+170	460	600	+140
7	480	640	+160	470	600	+130
8	490	630	+140	440	640	+200
9	560	600	+ 40	590	660	+ 70
10	560	610	+ 50	550	730	+180
11	700	630	- 70	620	680	+ 60
12	550	640	+ 90	550	840	+240
13	590	550	- 40	650	700	+ 50
14	490	630	+140	460	640	+180
15	390	530	+140	460	580	+120
16	330	590	+260	440	660	+220
17	460	520	+ 60	480	750	+270
18	480	500	+ 20	590	730	+140
19	550	740	+190	530	810	+280
20	470	660	+190	470	650	+180
Mean	490	616	+126	521	688	+167
+ SD	80	69	98	94	90	74
p < 0,0001						

The EMG activity of the oblique abdominal muscles was recorded during maximum voluntary contraction, before and after training.

The values of three subjects had to be excluded because of technical interference during the recordings. The average increase in the remaining 17 subjects was 42%. The difference is significant ($p < 0,01$).

Trunk extension strength

The muscle strength was determined before and after training. Table I shows that all subjects had higher values after training of the abdominal muscles. The average increase from 521 to 668 N (32%), was highly significant ($p < 0,0001$).

The EMG-activity of the back muscles was recorded during maximum voluntary contraction, before and after training.

Two subjects had to be excluded for technical reason. Out of the remaining eighteen, twelve showed an increased EMG activity after training. The average increase for the eighteen subjects was 15%. The difference is significant at the 5% level.

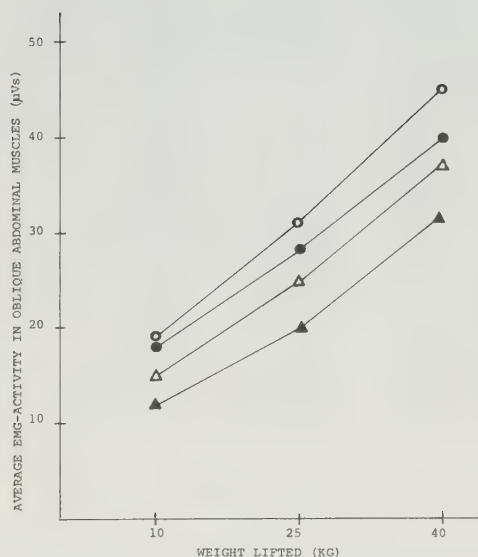


Fig.7. The activity of the oblique abdominal muscles at lifting during 0,3 s. before the peak of the IAP. The mean activity at different techniques of lifting and different loads, before and after training.

- | | |
|----------------------------|-----------------------------|
| ○ leg lift before training | △ back lift before training |
| ● leg lift after training | ▲ back lift after training |

Recordings during lifting

1. The activity of the oblique abdominal muscles when lifting was estimated for the time period when the IAP is built up, i.e. especially the period before the peak of the IAP. For this reason, the EMG was measured for 0,3 s and 0,6 s - in some cases also for 0,9 s - before that peak. We also deter-

mined the position of the peak activity of the abdominal muscles, relative to the total time of the lift. Fig. 7 shows that the activity increases with an increase of external load. The figure demonstrates this fact for the period of 0,3 s before the peak of the IAP, but the same holds true whether the activity is measured for 0,3, 0,6 or 0,9 s before the peak of the IAP. The figure also shows that the activity of the oblique abdominal muscles decreases after training. The decrease occurs at all the types of lifts examined, and the difference in the whole material is highly significant ($p = 0,001$). Fig. 7 also shows that this activity of the oblique abdominal muscles is throughout higher at leg lifts than at back lifts, both before and after training. The difference is significant in both cases ($p = 0,01$ and $p = 0,0001$ respectively). Leg lifts and back lifts also exhibit other interesting differences to be discussed below in connection with patterns of movement.

2. *The intra-abdominal (intragastric) pressure (IAP).* The IAP shows a characteristic variation for the type of lifts studied. In the beginning of the lift the pressure rises more or less steeply to a peak, after which it descends to a level at or immediately above the pressure in the upright position without load, although the subject is now holding a load of varying weight in his hands. During the lowering, the pressure rises comparatively slowly to form another peak before the end of the lowering, whereupon the pressure quickly returns to its basal level. The curve varies between the subjects, and in one subject between lifts with different weights, as regards the height of the peak and their position in time during lifting and lowering, but the shape of the curve remains practically the same in all lifts of the same type (Figs. 4 and 5).

The IAP when standing at rest varies between 0.3 and 2.0 kPa (mean value 0.9 kPa) before training and between 0.1 and 2.0 kPa (mean value 1.3 kPa) after training.

The peak value of the IAP during lowering varies in roughly the same way as the corresponding value during lifting, though

throughout at a somewhat lower level. The quantitative calculations were therefore concentrated to the lifting which was estimated as regards *both* the peak value *and* its position in time relative to the total lifting time.

The IAP was compared before and after training (Fig. 8). It was then found that, in the whole material, there was no difference between lifts before and after training, whether they were leg lifts or back lifts. The average difference when lifting is 0,3 kPa in the whole material.

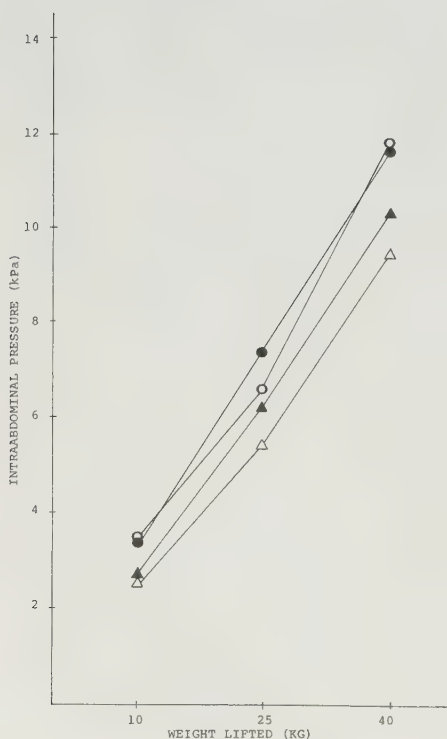


Fig. 8. Peak values of intra-abdominal pressure at lifting 10, 25, and 40 kg before and after training.

- | | |
|----------------------------|-----------------------------|
| ○ leg lift before training | △ back lift before training |
| ● leg lift after training | ▲ back lift after training |

There are, however, certain individual differences as regards the effects of training. We studied whether those four sub-

jects who had a markedly raised IAP after training, differed in any respect from the whole group. Those who had started with the strongest trunk flexors tended to show the greatest rise of the IAP. The difference between subjects with strong and weak trunk flexors was, however, not significant.

The IAP when lifting varies considerably between different individuals (Figs. 9 a, b). Back lifting of 25 kg may for instance produce an increase of the IAP to between 2,8 and 11,1 kPa, and leg lifting of 40 kg an increase to between 7,5 and 21,3 kPa. In each separate individual the pressure increases, however, with the increase of load.

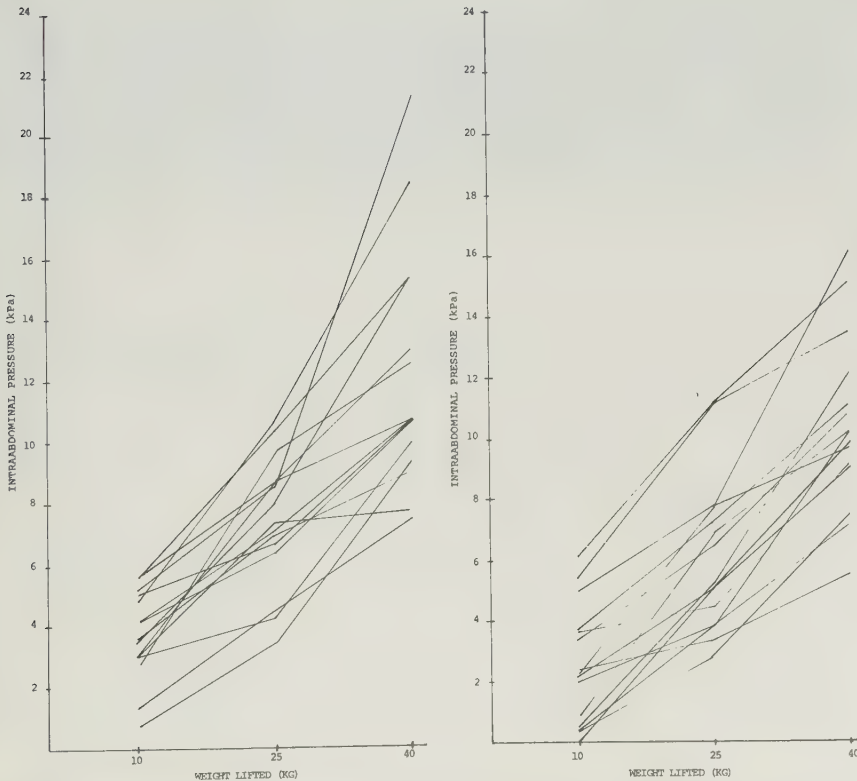


Fig. 9. Peak values of intra-abdominal pressure at lifting 10, 25, and 40 kg. (a) Leg lifting. (b) Back lifting.

Each line represents one subject. The individual variations are considerable.

Throughout, the IAP is higher at leg lifts than at back lifts (Fig. 8). The difference is significant for all weights, both before and after training ($p = 0,01$ in all cases).

3. *The relation between the activity of the oblique abdominal muscles and the IAP.* It was previously stated that both the activity of the oblique abdominal muscles and the IAP rises with an increase of the external load. To determine if there is a causal relationship between the two parameters, i.e. if the activity of the abdominal muscles might be the cause of the increase of the IAP, we studied their relations to each other as regards a connection both in time and in quantity before and after training.

The time intervals between the maximum activity of the oblique abdominal muscles and the maximum of the IAP vary between 0,2 and 0,4 s at leg lifts and between about 0,8 and 1,4 s at back lifts. The isometric training did not affect these relations in time.

Table II. Relation between change of oblique abdominal muscle activity and change of intraabdominal pressure after training.

Technique	Weight	Average change		r	p
		EMG (μ Vs)	IAP (kPa)		
Leg lifting	10	-1,0	-0,39	-0,27	NS
	25	-1,6	+0,76	+0,17	NS
	40	-5,4	-0,55	+0,19	NS
Back lifting	10	-8,3	-0,03	-0,12	NS
	25	-2,9	+0,50	-0,04	NS
	40	-4,9	+0,87	+0,21	NS

The coefficient of correlation was calculated between, on the one hand, the change of activity of the oblique abdominal muscles, and on the other hand, the change in the IAP before and after training in each individual (Table II). On no occa-

sion did the coefficient of correlation deviate significantly from zero, which means that no co-variation can be shown for those two variables. It thus seemed as though an increase or decrease of the activity of the oblique abdominal muscles did not result in a rise or fall respectively of the IAP.

4. *The activity of the erector spinae muscle.* The activity of the erector spinae muscle was studied both by measuring the myoelectrical activity during 0,3 s when the IAP reached its peak, and by recording the time for the beginning and end of muscular activity and for its peak relative to the start of the lift. These recorded times were then related to the total time of each lift.

The myoelectrical activity of the erector spinae muscle recorded during the above mentioned 0,3 s rises with increased weights (Fig. 10). The activity after training shows no significant difference compared to that before training.

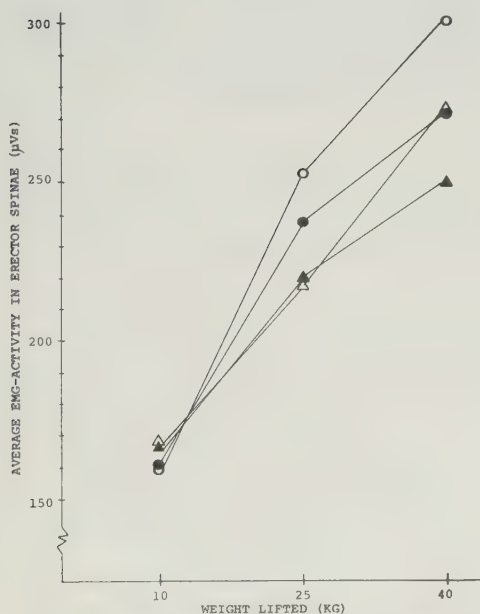


Fig. 10. The activity of the erector spinae at lifting during 0,3 s around the peak of the intra-abdominal pressure. For explanation cf. Fig.7.

There is a clear difference between leg lifts and back lifts as regards the time when the activity of the back muscles start and reaches its maximum and when the activity ceases at lowering (Fig. 11). At leg lifts the activity of the back muscles starts throughout before lift-off. The activity then increases successively, reaches its peak about the middle of the lift and lasts, in most cases, up to touch-down. In back lifts, the activity starts considerably later, after 3-17% of the total time of the lift. The activity increases more slowly and reaches its peak towards the end of the lift. At lowering, the activity of the back muscles ceases long before touch-down while still 27-48% of the time of lowering remains. Figure 11 also shows that the activity of the back muscles tends to start earlier and cease later when the weight is increased.

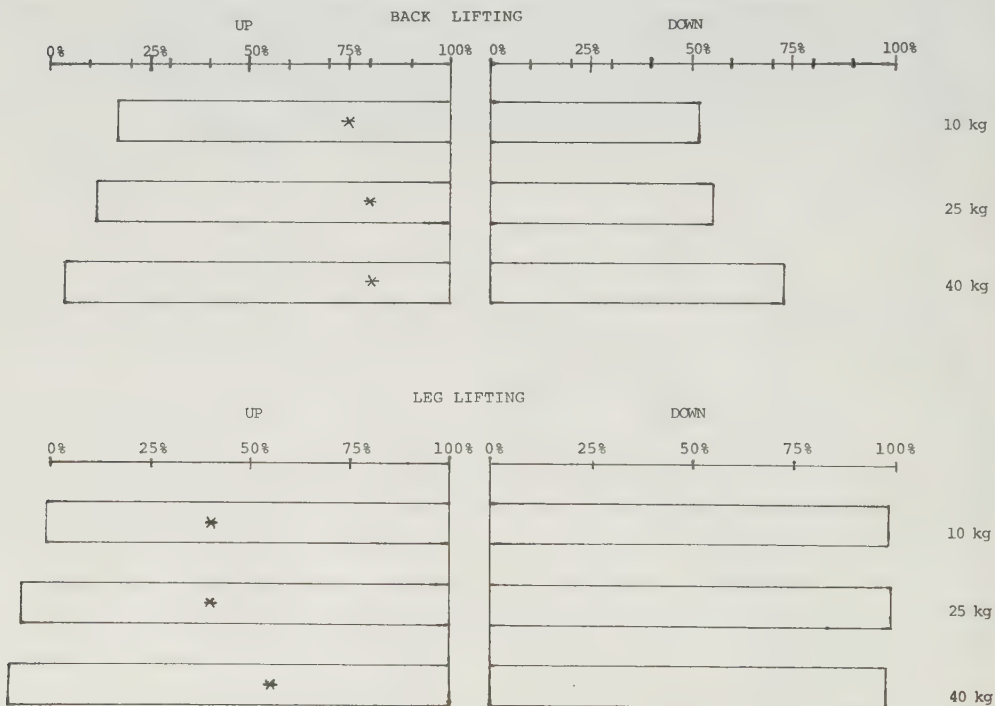


Fig. 11. The duration of myoelectric activity of the erector spinae at different techniques of lifting and different loads in percentage of the time for lifting and lowering. Mean values for all subjects ($n=20$) during all lifts. Scattered area = myoelectric activity registered. Scattered area to the left of the scale means activity before the box begins to move upwards. * maximum of activity.

5. *Lifting time and patterns of movement.* The lifting time of leg lifts was on the average 1,9 s and of back lifts 2,0 s. After training these times were significantly reduced by about 10% for both types of lifts, independently of the weight of the load ($p < 0,01$). The total time of lowering was on the average 1,6 s both in leg lifts and back lifts. This time was not significantly affected by training. The time of lifting did not change whether the load was 10 or 25 kg. Lifts of 40 kg were, however, 0,2-0,3 s slower than those with lighter loads.

The pattern of movement at lifting was analysed by studying the mutual relations between the peak value of the IAP, the maximum activity of the oblique abdominal muscles and the erector spinae, and the start of activity of that muscle. Those times were related to the total time of lifting.

At leg lifts, the peak of activity of the abdominal muscles appeared after 20-30% of the total time and the peak value of IAP after 35-45% of that time. At back lifts, the activity of the abdominal muscles reached its peak roughly at the start of the lift while the peak of the IAP appeared after 45-55% of the time of the lifting.

The training produced, apart from a shortening of the total time, no significant displacement of the peaks of the IAP or the maximum activities.

It should finally be mentioned that at leg lifting myoelectrical activity was, of course, always to be found in the lateral vastus muscle, and always more when lifting than when lowering. At back lifting, there was no activity that could be recorded with cases where the subject could not reach the box on the floor with straight knees.

DISCUSSION

The strength of the trunk muscles may be measured in different ways - isometrically or isokinetically, in the upright position or in the supine, prone or lateral supine position and it may also be assessed with different scales of estimate, such as Janda's 5 degree scale. We chose a method of measuring which has previously been used in several investigations (e.g. 3, 31).

In an isometric trunk flexion strength test all the trunk flexors and hip flexors are activated, and also the trunk extensors and hip extensors as stabilizers. The only muscles that can exert a forward bent torque in our test position are the rectus abdominus, the external and internal obliques and the psoas, as the motion axis is shown to be located about the intervertebral disc L3-4. The psoas, however, here works at a mechanical disadvantage and Alston and others (1) also showed that the psoas muscle is responsible only for about 10% of the force in ventral flexors in subjects without symptoms from the back. The other hip flexors only stabilize the pelvis as that part does not move during the test. Thus we may conclude that we have mainly tested the strength of the rectus abdominis and the two oblique abdominal muscles.

Similary, in trunk extension not only the back extensors but also the hip extensors are activated. These muscles can, however, hardly exert any considerable force against a strap around the upper part of the trunk.

When lifting weights below 45 kg the rectus abdominis muscle is only slightly activated (22). Instead the oblique abdominal muscles are active when lifting and through their anatomical position might raise the IAP on contraction. In this investigation we could confirm the observation that the oblique abdominal muscles are activated by isometric training and in tests of isometric strength, but there is no possible way of measuring the force from the oblique abdominal muscles by it-

self. It can be assumed that the effect of training in this study comprises all abdominal muscles, both rectus and oblique ones. Nothing is known about the activity of the transverse abdominis muscles during lifting and training.

As was expected the strength of the abdominal muscles increased considerably between the two examinations (average +26%) which must be attributed to the very intense training. The effect was highest in those subjects who had been weakest from the beginning and least in those who had been strongest as is usually the case in muscle training and thus expected.

Electromyographic recording of the oblique abdominal muscles when measuring the strength after training, showed a markedly increased myoelectrical activity (average +41%). This indicates that the training resulted in improved recruitment of motor units.

The scale of estimate according to Janda proved unsuitable in these healthy young men who already before training achieved the highest value in 16 out of 20 cases.

Further support of the conclusion that the strength of the abdominal muscles really has increased in the subjects, can be found in the fact that the training load could be successively increased during training (Fig. 6).

The strength of the back muscles was also found to be noticeably increased after training. This is more difficult to explain. Using EMG control, we could see that the erector spinae muscle was not activated during training. The increase in EMG activity found during maximum voluntary contraction is relatively modest as compared to the increase of strength. This indicates that only a minor part of the difference can be explained by an improved recruitment of motor units due to a general physical activation. Part of the increase in strength is probably only apparent and might be due to faults in the recording technique. Isokinetic measurement of back muscle

strength has shown that the position of the trunk is of utmost importance (30). The question naturally arises whether there are similar sources of error when measuring the strength of the abdominal muscles. In that case, there are, however, several arguments (such as increased EMG activity in tests of strength, increased training load) in favour of a real increase of strength in the abdominal muscles.

The EMG recordings in this study were made with surface electrodes, as they offer the best reproducibility at repeated recordings (18, 33). The electrodes over the oblique abdominal muscles record mainly the external oblique muscle as it is closest to the electrodes, but some activity from the internal oblique is certainly also picked up. The two oblique muscles work together functionally in symmetric movements on the sagittal plane (27). The possible importance of the transverse muscle is not very well investigated. Wire electrodes would have offered more selectivity for separate muscles but also less reproducibility.

Jonsson (17) showed that deep and surface back muscles always work simultaneously in a flexed position.

The activity of the abdominal muscles when lifting was calculated during 0,3 s before the peak of the IAP, since this activity is the most interesting as regards the effect of abdominal muscles on the IAP. It appears that this muscle activity increases with increased loads, before as well as after training. On the other hand, the myoelectric activity shows lower values after, as compared to before training. Earlier, we found that the strength of the abdominal muscles increases and so does the EMG activity of the oblique abdominal muscles on maximal load after training as a sign of an increased recruitment of motor units. It is, however, to be expected that muscle training also results in an improved metabolism of the muscle cells, so that a given muscular work can be performed with less motor units. The newly acquired ability of recruiting a larger number of motor units is, thus, not made use of.

during lifting. This might be due to the circumstance that the training of abdominal muscles is mainly isometric, whereas lifting and lowering is a dynamic process of eccentric and concentric contraction.

The abdomen acts as a cavity with gaseous, fluid and semi-solid contents where pressure variations are evenly transmitted in all directions (25). The intragastric pressure follows the intra-abdominal pressure very closely and differences between the different parts of the abdomen are solely due to hydrostatic differences (5).

Our system for measuring the IAP by means of an open polyethylene catheter has for many years been used for measuring the intragastric pressure (29). It has the advantage that technical faults are easily discovered and that the functional ability can be checked by flushing the catheter. Pressure measurement by means of a balloon catheter appears to be less reliable (32). By measuring the IAP at lifting movements with or without weights in the hands, it is possible to calculate what part of the changes of the IAP is due to the position of the trunk and what part to the load lifted. Comparative calculations at different lifting techniques and different loads before and after training show no differences of importance with regard to pressure changes due to body position. All values in this study thus refer to the peak value of the IAP as measured in each lifting situation with no correction for trunk position.

The IAP at lifting rises almost linearly with the increase of weights at least up to 40 kg. In this respect, the result agrees with previous investigations (4, 11, 22).

As regards the effect of training of the abdominal muscles, we found no statistically significant change of the IAP when lifting after training. This agrees with results reported by Legg (21). Out of twenty subjects, only four had an increase of pressure more than 2 kPa - an increase which might be impor-

tant from a biomechanical point of view, whereas other subjects had an unchanged or even slightly lowered IAP when lifting, although the strength of the abdominal muscles had increased considerably.

The IAP showed large individual variations with the same external load. The difference cannot wholly be explained by dissimilarities of body size or the levers of the loads, and should, therefore, be more closely studied.

In this investigation, leg lifts produced higher IAP than back lifts with all weights, both before and after training. This agrees with results published by Morris et al. (22). It cannot be determined whether the difference is due to variations in the length of levers or to other factors.

Several authors have found that both the activity of the oblique abdominal muscles and the IAP increase with the increase of external loads (19, 22). Kumar (20) found a very strong correlation between the peak values of the IAP and the EMG activity of the oblique external muscle ($r = 0,92$ for sagittal lifts). This does not, however, prove a cause - effect relationship between the activity of the abdominal muscles and the IAP.

By comparing changes in the activity of the abdominal muscles and changes in the IAP at the same type of lifts by the same subject before and after training, it should be possible to show a co-variation if there is a causal relationship. Our results do not indicate a causal relationship. The IAP must be considered to be dependent on several cooperating factors only one of which is the activity of the abdominal muscles as already suggested by Kumar (19) as regards stoop lifting.

There were definite differences between leg lifts and back lifts in our study. The myoelectrical activity of the oblique abdominal muscles was thus, throughout, greater in leg lifts, the IAP was higher and there were marked differences as re-

gards the activation of the back muscles. In leg lifts, the activity of the back muscles started throughout before the box began to move upwards, it was then successively increased to reach its maximum between 0,7 and 1,0 s and lasted until the end of the lifting. In back lifts, the activity began considerably later, between 0,1 and 0,3 s after the start of the lift, increased more slowly and reached its maximum about 1,5 s after the start of the lift. In the lowering there was a corresponding and even more pronounced difference. The activity of the back muscle ceased relatively earlier during the lowering. The results agree with earlier investigations (7, 14, 26). This phenomenon is probably important with an increased risk of overtaxing the non-contractile structures of the back in the first phase of the lift and the last part of the lowering, respectively.

There was another interesting difference between leg lifts and back lifts. In back lifts, the activity of the abdominal muscles appeared very early in the lift, whereas activity was lower at the peak of the IAP. This lack of coordination between the activity of the abdominal muscles and the IAP may be of importance for the development of hernias, e.g. inguinal hernias that sometimes occur on heavy lifting (10). In leg lifts, the situation was different as the activity of the abdominal muscles was maximal when the IAP was at its highest.

ACKNOWLEDGEMENT

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Intraabdominal Pressure during Lifting in Relation to Trunk Muscle Strength in Chronic Low Back Patients.

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INTRODUCTION

Strengthening of the abdominal muscles is generally considered essential in the prevention of low back pain. This idea is based on the assumption that low back patients have a reduced intraabdominal pressure (IAP) during the performance of heavy tasks, as lifting in forward bent positions, due to weak abdominal muscles. The IAP is suggested to reduce the load on the lumbar spine during lifting (22, 4, 8, 11, 10).

Several investigators (for references see 25) have studied the strength of trunk flexors and trunk extensors in healthy subjects and low back patients. There are also several studies on healthy subjects concerning the intraabdominal pressure during lifting (for references see 18) but only one (13) deals with IAP in low back patients. There is so far no study of trunk muscle strength and IAP during lifting in the same individuals, whether healthy or sick.

The aim of this study was therefore to compare trunk muscle strength and intraabdominal pressure during lifting in low back patients and in healthy subjects. The question also arose what we really measure by assessment of trunk muscle strength. We also wanted to compare the two groups with regard to the myoelectrical activity in the oblique abdominal and erector spinae muscles during lifting.

MATERIAL

Twenty male construction workers with chronic low back pain were selected from the unions' lists of members and previous case records from our medical health service (Table I). They were not under medical care at the time but had had more or less continuous low back pain for 2-18 years (median 5,5 years). Five subjects had been sicklisted during the last year, one was rehabilitated from carpenter to supervisor due to back pain, but otherwise they had apparently learnt to live with their complaints. Twelve out of the twenty stated that they

tried to be cautious and avoid heavy lifts. On examination they were found to suffer from lumbar spine disorders without sciatica or any other complicating diseases. None had been operated upon due to back disease. Reflexes at the lower extremities were normal.

Table I. Characteristics of the low back patients and the healthy controls.

		Low back patients	Controls
Number		20	20
Age (years)	mean	32	28
	range	22-37	23-33
Height (m)	mean	1,80	1,80
	range	1,74-1,88	1,71-1,87
Weight (kg)	mean	76	75
	range	57-89	68-86
Occupation			
Electrician		13	20
Carpenter		4	-
Supervisor		2	-
Painter		1	-
Physical activities in leisure time (du- last 3 months):			
None		18	12
Physical activity 1-3 h/week		2	6
Soccerfootball (amateurs)		-	2

Eight low back patients had previously been treated by a physiotherapist individually or in group (so called Back school) but only one of them was still doing abdominal muscle exercises 2-3 times a week. One of the patients had been using a corset in leisure time for six years, and another a weightlifter's belt for six months.

Twenty healthy subjects with no history of back pain served as controls (Table I) and were examined in the same way as those with pain. One of the controls had done some abdominal muscle exercise during the last year before the examination.

METHODS

Assessment of spinal flexion and straight leg raising test.

Measuring of spinal flexion was performed according to recommendations from the American Academy of Orthopaedic Surgeons (2). Table II shows the increase of distance C7-S1 from standing erect to bending forward and the distance between fingertips and floor during maximum forward flexion. In the straight leg raising test the angle between the table and the straight leg was measured with a goniometer.

Table II. Spinal flexion and straight leg raising test.

	Low back patients	Controls
	20	20
Increase of distance C7-S1		
6 - 8 cm	7	4
9 - 11 cm	13	14
12 - 14 cm	0	2
Distance between fingertips and floor		
≤5 cm	11	7
6 - 14 cm	5	4
≥15 cm	4	5
Straight leg raising test		
Symmetrical 70 - 75°	7	7
- 80°	8	11
85 - 90°	3	2
Asymmetrical >10° diff	2	0

Assessment of trunk flexion strength

Measurement of the strength of the trunk flexors was carried out in the upright position (Fig. 1).

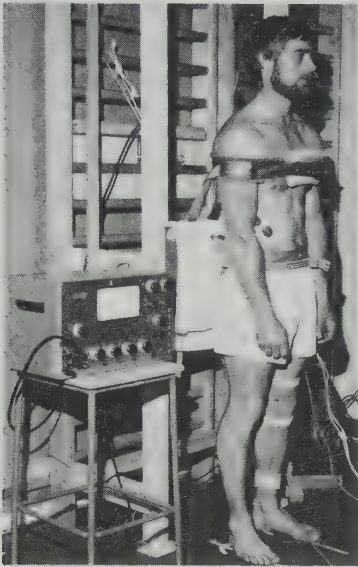


Fig. 1. Subject preparing to measure trunk flexion strength. The strain gauge is situated behind the frame. The figure also shows the electrodes over the oblique abdominal muscles.

A special frame was made with a support behind the pelvis. The strap of the recording instrument was placed across the chest and upper arms at the level of the attachment of the deltoid muscles. The tension in the strap was recorded by means of a strain-gauge. Each subject had to do 3 maximum isometric ventral flexions with a duration of at least 3 seconds. The estimates were then made from the median values.

The measuring was carefully standardized to permit comparisons. The subjects were told to do a trunk flexion and not a hip flexion and their minute movements during the test were supervised. The position of the feet in relation to the frame was also standardized. The healthy controls, who had taken part in a previous investigation (18), were reexamined in the same manner as

the low back patients to get comparable values. (Three failed to appear).

Assessment of trunk extension strength

Measuring of the strength of the trunk extensors was performed with the same method, except that the subject faced the frame with the strap placed across the dorsal part of the chest and the upper arms at the same level as before.

Intra-abdominal pressure recordings.

The intraabdominal (i.e. intragastric) pressure was recorded via an open polyethylene tube as was previously described (18). In the case of the patients the tube was connected to a pressure transducer (Bentley Trantec) and the variations of pressure were transmitted via a pressure amplifier (BM Elektronik, Åhus, Sweden) to a tape recorder (Racal Store 14 FM) for subsequent analysis in a computer. The pressure curves were continuously checked on a mingograph (Siemens 82) and the tube flushed with saline when necessary.

Electromyographic recordings

The low back patients were supplied with disposable electrodes (3 M Red Dot 2247 Ag/AgCl) over the right erector spinae muscle at the L2-L3-level (3 cm lateral to the spinous processes) and over the right oblique abdominal muscles at umbilical level and above the ventral iliac spine. The skin was prepared in the prescribed manner with the enclosed piece of sandpaper and alcohol. The interelectrode distance was 5 cm and the direction of the electrodes parallel to the direction of the muscle fibres. The myoelectric signals were fed to preamplifiers fastened to the patient's waist. The signals were further amplified and recorded on magnetic tape. During recording the signal quality was continually checked on a mingograph. For analysis, the myoelectric signals were full-wave rectified and integrated over a preset period, throughout this study 0,1 s. The upper and lower cut-off frequencies were 1000 and 50 Hz respectively. An active T-filter was used with a slope of 12 dB/octave.

The myoelectrical recordings in the healthy controls have been described previously (18).

The examination procedure

Each subject was asked to carry out three trunk flexion strength tests, three trunk extension strength tests and a series of symmetric lifts from floor to upright position with the load on extended vertical arms in front of the body (fig. 2). Each lift was done twice and all calculations were made from the mean value of the two lifts. The subjects were allowed to rest between lifts.



Fig. 2. Example of back lift 40 kg, Note the switch at the bottom of the box, the electrogoniometer on the left knee and the pressure recording system. The EMG electrodes are situated on the subject's right side. Part of the upper switch is seen on the top of the picture.

Lifts were done with 10, 25, and 40 kg, in all cases with leg lifting as well as back lifting. By leg lifting is meant lifts with bent knees and the back as straight as possible. Back lift was used of lifting with straight knees and bent back.

Each subject could choose his own lifting speed and breathing technique, but otherwise the lifts were carefully standardized

to facilitate comparisons between the low back patients and the healthy controls. The subject stood in a fixed position relative to the load and a physiotherapist gave instructions about the lifting technique to be used.

The subjects were asked to report any pain during or after a strength test or a lift. If there was any fear that the pain would prove too severe, that particular test or lift was excluded, to avoid all risks.

In all lifts, a specially made box was used (40x25x16 cm), that could be symmetrically loaded with 5 kg weights. Attached to the box were an accelerometer for recording vertical acceleration and a switch for recording the start of the lifting and the end of the lowering. Another switch was placed behind the subject at the Th3-4 level when standing erect, recording the end of the lift and the start of the lowering.

With the low back patients the lifts were also controlled by an electrogoniometer on the left knee.

STATISTICAL METHODS

Routine statistical methods were used. The strength of the covariance was determined by Pearson's correlation coefficient, r . The analysis of significance of differences was carried out according to Student's t -test.

RESULTS

Trunk flexion strength

The low back patients exhibited reduced trunk flexion strength as compared to the healthy controls (Table III). The difference was highly significant ($p = 0,001$). When attempting to test flexion and/or extension strength three patients reported pain and were excluded.

Table III. Maximum trunk flexion strength and trunk extension strength (mean values and range within parenthesis).

	Low back patients	Healthy controls	p
n	17	17	
Trunk flexion strength (N)	549 (350 - 830)	721 (460 - 1010)	0,001
Trunk extension strength (N)	821 (660 - 1200)	859 (660 - 1070)	N.S.
Extension/flexion ratio	1,54 (1,08 - 2,17)	1,29 (0,88 - 2,15)	0,015

Trunk extension strength

The two groups showed no differences either in trunk extension strength (table III) or in reported pain.

Extension/Flexion - ratio

The ratio was determined for each subject by dividing the extension strength by the flexion strength. The mean ratio of the low back patients was 1,54 and of the healthy controls 1,29 (table III). The difference was significant ($p = 0,015$).

Intraabdominal pressure during lifting

There was no difference in IAP during lifting regardless of weight or lifting technique (fig. 3 a + b).

As it was a main concern to avoid any injury to the patients, only five lifts by three patients were reported to be painful, out of about 200 lifts. No pain was reported in the control group.

Trunk muscle activity during lifting

As the two groups were examined with different electrodes, they could not be compared quantitatively. Within the groups the different tests may, however, be roughly compared if it is ta-

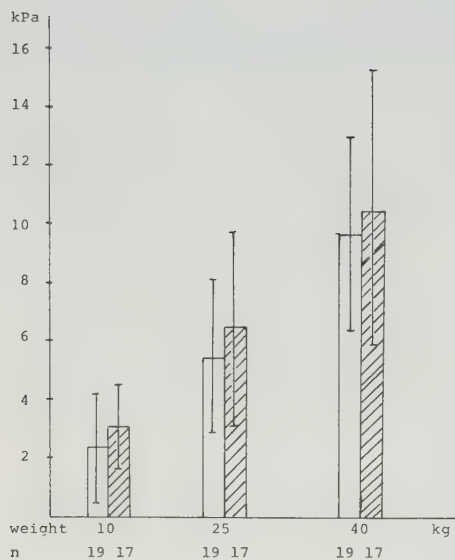


Fig. 3 a. Back lifting.

Peak values of IAP at lifting 10, 25, and 40 kg (mean $\pm$ SD).

□ Healthy controls ▨ Low back patients

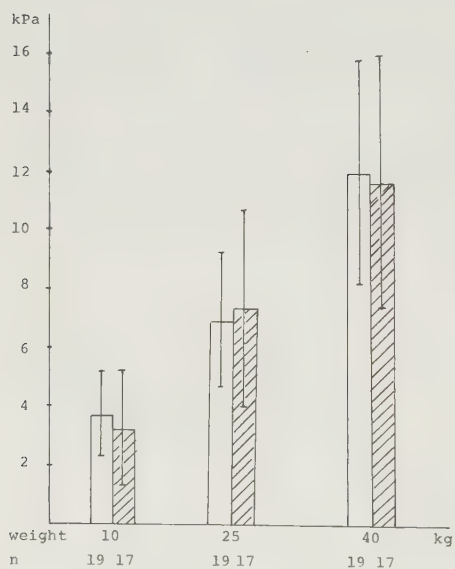


Fig. 3 b. Leg lifting.

Peak values of IAP at lifting 10, 25, and 40 kg (mean $\pm$ SD).

□ Healthy controls ▨ Low back patients

ken into consideration that the strength test is isometric while lifting contains concentric and eccentric contractions.

During the lifts of 25 kg, leg lifts or back lifts, the activity of the oblique abdominal muscles was only 5-15% of the maximum activity during the trunk flexion strength test. During the lifts of 40 kg the corresponding figure was 15-25%.

The erector spinae was relatively more active during the lifts. With 25 kg, the activity was 40-60% of the maximum recorded during the trunk extension strength test. For 40 kg the corresponding figure was 50-75%.

In these respects, there were no significant differences between the two groups.

There was, however, a clear difference in the duration of activity during the back lifts. Figure 4 shows the duration of detectable erector spinae activity (sensitivity 600 - 1000 $\mu\text{V}/\text{cm}$) in percentage of the total time of lifting and lowering respectively. There was a significant difference as the low back patients started activating their erector spinae muscles earlier and moreover, the activity lasted longer during the lowering.

The ability to reach the floor in forward bending (distance fingertips to floor in table II) was compared in back lifting to the relative duration of erector spinae muscle activity during lifting and lowering (fig. 4). We found a weak positive correlation between stiffness and duration of activity. For the patients r varied between + 0,37 and + 0,56 for lifting or lowering of different weights (p 0,05 for lifting 10 kg and 25 kg) and for the healthy subjects between + 0,12 and + 0,42 (NS). This seems to suggest, that the stiffer subjects started activating their erector spinae later during lifting than the more mobile ones and they also ceased activating their muscles earlier during lowering.

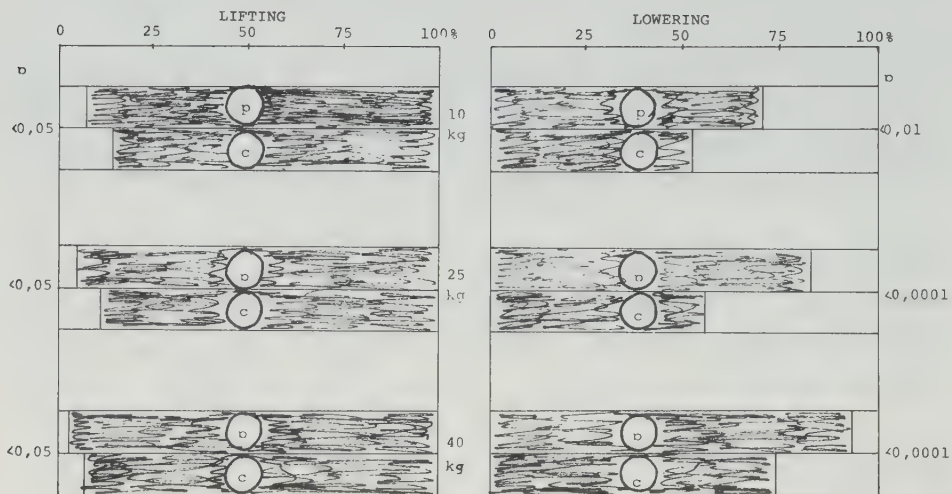


Fig. 4. The duration of myoelectric activity of the erector spinae at back lifting with 10, 25, and 40 kg in percentage of the time for lifting and lowering. Scattered area = detectable myoelectrical activity (means and p-values for the difference between the patients (P) and the controls (C)).

The low back patients and the healthy controls are fairly equal as regards this mobility.

The other mobility test (C7 - S1-distance) and straight leg raising test gave too small ranges to allow any calculations.

DISCUSSION

The main purpose of this investigation was to study the relationship between trunk muscle strength and intraabdominal pressure during lifting in low back patients compared to healthy controls. Furthermore we wanted to illustrate some features in the trunk muscle activity during lifting that might have clinical implications.

Trunk flexion strength test

Concerning trunk muscle strength we first have to discuss what forces we really measure during these tests. The test situation was exactly the same for the two groups, which is essential. They were all standing upright, to exclude the effect of gravity (26) and to minimize the effect of variations in maximum torque produced during trunk flexion and trunk extension (26). Their heights and weights were quite equal, they were all barefoot with approximately the same angle leg-floor to minimize variations in friction against the floor. The same personnel instructed and supervised the subjects during the tests.

When this technique is used, the bilateral axis of motion is located about the intervertebral disc L3-4 during trunk flexion test (18) and ventrally to L 1-2 during trunk extension test. This means that only the anterior abdominal muscles and to a minor degree perhaps the psoas can exert a forward bending movement against the strap. The other hip flexors and all the hip extensors balance each other in stabilizing the pelvis, provided that it does not move, which may be detected during the test. The psoas muscles account for 5-9% of the trunk flexion strength, according to Alston et al (1), but Farfan (14) calls attention to the fact that no digitation of the psoas can exert a bending moment between 15° of extension and 65° of flexion.

Among the abdominal muscles the rectus abdominis, the ventral portion of the external oblique and most of the internal oblique may be responsible for a forward bending movement (14). The transverse abdominal muscle cannot contribute due to its anatomical position.

As the test is isometric we always have to take into consideration that the antagonists - erector spinae muscles - may be more or less activated simultaneously. In fact our back patients exhibited an average erector spinae activity during the flexion test amounting to 14% of their maximum activity during the extension test, and the healthy controls about the same relative activity. This antagonist activity has not been consi-

dered before, to our knowledge.

Furthermore the intraabdominal pressure was elevated during the trunk flexion test. (Mean 11,7 kPa, SD = 4,3, among the patients and 10,5 kPa, SD = 6,1, among the controls). This pressure rise has been reported in corresponding situations, such as push and pull 20-40 kg (9) and upright horizontal loading (17) but not in connection with maximum trunk strength test, though discussed by some authors (21, 25).

In summary we may conclude that the rectus abdominis, the external and internal oblique abdominal muscles have to overcome the extending moments from the erector spinae and the intraabdominal pressure during the trunk flexion test and that we measure the net effect on the strain gauge provided that the pelvis and the lower extremities can be kept immobile by the hip flexors and extensors and, of course, the other leg muscles.

Morris et al (22) calculated that 14,1 cm² of the oblique abdominal muscles (= 50% of the whole muscles) and 8,4 cm² (= 100%) of the rectus abdominis act in a longitudinal direction. We cannot measure the strengths of the separate muscles but we may estimate that the oblique muscles account for a considerable part of the flexion strength, and consequently also for a great share of the loss of strength among the low back patients.

Trunk extension strength test

Concerning the trunk extension test we must consider the effects of the antagonists and the IAP. The average oblique abdominal muscle activity was for the patients 37% and for the controls 39% out of their respective maximum activity during the flexion tests. This seems to agree with Carlsöö (7) who reported "strong" activity of the external oblique muscle in the same test. We did not record the rectus abdominis muscle but Carlsöö (7) stated that - in healthy subjects - the rectus abdominis was activated only occasionally and then only slightly during the trunk extension strength test. As the axis of motion was located ventrally to the L1-L2 segment we may assume that a

certain amount of the oblique muscles work antagonistically to the trunk extensors during the test.

The maximum IAP during the trunk extension test was rather high (mean 16,0 kPa, SD = 4,1 among the patients and 11,3 kPa, SD = 5,0 among the controls). As for the axis of motion the lever of the IAP will probably be rather small.

Thus, the erector spinae muscles as prime movers have to overcome the flexing moment of the oblique abdominal muscles, perhaps with some help from an extending moment of the IAP.

Trunk muscle strength in low back patients and controls.

Our two groups appeared to be quite comparable in age, height and weight and fairly comparable regarding loads at work or leisure, as far as could be assessed from interviews and knowledge about their work.

The difference in average age - 32 years for the patients, 28 for the controls - cannot, according to Asmussen et al (3) explain any difference observed in strength.

Pain may be a confounding factor in any strength test, or even fear of pain. Our low back patients were not acutely ill at the moment except for three of them who felt pain during either the flexion or extension test or both. These painful recordings were excluded. The remaining 17, like the healthy group, reported no pain during the tests. In fact, in their experience the risk of pain was greater at extension test than at flexion test. It thus seems less probable that the difference in strength should be due to pain during the tests.

From biomechanical considerations we may conclude that our low back patients had a reduced trunk flexion strength due to weaker abdominal muscles than the healthy controls, as the extending moments from the IAP and from the erector spinae muscles were about the same for the two groups. Unfortunately we could not compare the myoelectrical activity between the two groups

so we cannot decide whether the reduced strength was caused by muscular or neurophysiological disturbances (e.g. inhibition). This considerable difference in strength (25%) should also affect the oblique abdominal muscles which have been believed to be important for the IAP during lifting.

It will thus be seen that a reduced abdominal muscle strength should diminish the antagonist activity during trunk extension test and accordingly increase the load on the strap provided that the extensors are equal. The higher IAP among the back patients should, if at all, act similarly. In addition, the reduced abdominal strength should strengthen the effect on the extension/flexion ratio compared to the absolute values. This was not so, judging from the p-values. This apparent discrepancy may be occasioned by a reduction also of the extensors or some horizontal dislocation of the bilateral axis of motion.

If the extensors were really weakened in the back patients, then, the flexors should in fact be even more impaired than was shown by the strain-gauge in the trunk flexion test.

We used the same strength test technique as i. a. Asmussen et al (3) and Tornvall (27) and, with modifications, Nordgren et al (24), Nachemson-Lindh (23) and McNeill et al (21).

Our results for the healthy groups agree with those of Asmussen et al and Nordgren et al. Tornvall examined young conscripts (19-20 years old) who were apparently weaker than our construction workers. The values reported by Nachemson-Lindh and McNeill et al are lower.

The extension/flexion ratio is for corresponding groups of healthy subjects: Asmussen et al 1,36, Tornvall 1,09, Nordgren et al 1,23, Nachemson-Lindh 1,11 and McNeill et al 1,37. Our figure 1,29 is thus consistent with previous studies with the same technique. In comparison the ratio for our patients (mean 1,54) seems to deviate.

There are several investigations on trunk muscle strength in low back patients (for review and references see 25). Some have found a selective decrease in trunk flexor strength (e.g. 23 for men 20-35 years) or trunk extension strength (e.g. 21) or both (e.g. 23 for men 36-55 years incapacitated more than one month or women 20-35 years). The differences may originate from different selections of patients, different methods and varying influence of pain.

Our low back patients were a selected group. The duration of their back complaints averaged more than 5 years, but they were all in full work, only 5 out of 20 had been sicklisted during the last year. Yet, they had a considerable reduction of the abdominal muscle strength, which we can neither explain, nor determine if it preceded or followed the back complaints.

Intraabdominal pressure during lifting

The next question concerns the IAP during lifting, The lifts were standardized so that conditions should be as equal as possible for patients and controls. Our equipment was tested in a model and under X-ray control (18) and our peak levels are fairly consistent with previous studies with similar lifts but other devices such as balloon-catheter (22), radio pill (20), and intragastric transducer (13).

We could find no difference between the groups regarding the peak IAP (fig. 3 a + b), in spite of the clear difference in abdominal muscle strength. Fairbank et al (13) did not assess the trunk muscle strength but measured IAP during 13 different lifts of 5 or 10 kg in different postures. Their findings from those loads and ours from lifting up to 40 kg are quite consistent for painless lifts. They found higher pressures during painful lifts. In our series, however, only five lifts were painful with very inconsistent values why no comments can be made on the effect of pain on IAP.

We may conclude that there appears to be no relationship between abdominal muscle strength and intraabdominal pressure du-

ring lifting.

Trunk muscle activity during lifting

Floyd-Silver (15) often found asymmetric trunk muscle activity. We always recorded from one side only and any asymmetry should be equalized among the lot of lifts.

Caution must be taken in comparing maximum activity during isometric contractions and myoelectrical activity during eccentric and concentric contractions during lifting. Nevertheless, the figures give a rough idea of the part played by the oblique abdominals in lifting and lowering. It is obvious that the oblique abdominal muscles were only slightly activated during these activities compared to the strength tests. This agrees with previous studies (12, 22). Morris et al (22) stated that the degree of activity in the oblique abdominal muscles during lifting of 90 kg was approximately one-sixth (about 17%) of that obtained with maximum voluntary contraction in the same position as that in lifting the weights.

The same conclusion applies even more to the rectus abdominis, which is usually fairly silent during lifts up to about 40-50 kg (12, 22).

In contrast to the slight activation of the anterior abdominal muscles we found that the erector spinae muscles, when engaged at all, were very active during lifting, that is 50-70% of maximum activity already with 40 kg. It seems that the capacity of the extensors may be a limiting factor.

It is well known since Floyd-Silver (16) that the erector spinae is often silent on EMG during maximum ventral flexion (the so called flexion-relation). Jonsson states this to be due to the interspinous and supraspinous ligaments being tightened and taking over the load from the erector spinae muscle (19). The activity ceases during flexion between 40 and 130° starts again when rising (6). Carlsöö supposes the variation between individuals to be related to elasticity and mobility (6). Both

in healthy subjects and low back patients we found a connection between the duration of the "flexion-relaxation" and the distance between fingertips and floor during maximum forward flexion, i.e. flexibility of the trunk and hips. This is in conformity with the statements of Jonsson and Carlsöö, but needs further studies on a larger material.

There was another interesting finding as regards the erector spinae activity, namely the clear distinction between the back patients and the controls. The patients kept up the activity of their erector spinae longer than the healthy men, especially during lowering.

We can only speculate about the clinical importance of this observation. Maybe it is this ability to use the back muscles that keeps them at work? Have they been forced to train their muscular coordination to spare joints and ligaments from further wear and tear?

It also remains to investigate if these back patients with the same IAP as the healthy subjects derive any advantage from their demonstrated ability to produce IAP rises during lifting in spite of weak abdominal muscles.

Acknowledgment:

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Intraabdominal Pressure and Trunk Muscle Activity during Lifting – Effect of Abdominal Muscle Training in Chronic Low Back Patients:

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INTRODUCTION

Abdominal muscle training is often recommended in programmes of primary or secondary prevention for low back pain (18, 19). It is in fact the only "home exercise" in the so called "Back school" (28). The aim of the training is to decrease the load on the vertebral column when at heavy tasks, such as lifting, by increasing the intraabdominal pressure (IAP) (18, 19) or by creating a "muscle corset" (28).

In a previous study we investigated the effect of isometric abdominal muscle training in healthy subjects (12). Legg also studied the effect of dynamic abdominal muscle training in healthy subjects (17). In neither of these studies was there any effect of the training on the intraabdominal pressure during lifting. We found, moreover, no increased activity in the oblique abdominal muscles during lifting, but on the contrary, a decrease.

The aim of this investigation was to study the effect of abdominal muscle training in chronic low back patients with regard to trunk muscle activity and IAP during lifting. In this study we were able to study the whole lifting procedure (from start to end of lifting and lowering) by computerizing the calculations. Otherwise the design of the study was similar to the previous one (12) to facilitate comparisons.

MATERIAL

Twenty male chronic low back patients from the construction industry were selected as previously described (13). Using the unions' lists of members and our previous case records from the medical health service for all construction workers in the city of Malmö, we picked out all cases of low back pain and appropriate ages, heights and weights among electricians, carpenters, painters and supervisors. From these 222 subjects we selected those

32 men who had most low back pain without sciatica, least physical activity in leisure and no other complicating diseases. Everything else being equal, we preferred an electrician before the others, as our previous healthy subjects were all electricians. Twenty-six men consented to take part in the investigation. Twenty of these were finally selected after medical examination. (13 electricians, 4 carpenter, 2 supervisors and 1 painter). Those excluded had signs of thoracic spine disorders or sacroiliac joint diseases and were treated.

Through this procedure - and knowledge about their work - we got a group of patients with a fairly uniform case history and as similar exposure to loads as possible, both at work and leisure. They all seemed to have chronic lumbar complaints with more or less continuous pain, which was aggravated by heavy work or by protracted static posture. On examination we found local tenderness and suspected instability in the lumbosacral and/or the adjacent lumbar segments. Hips and other joints and routine tests were quite normal in all cases. None had a suspected inguinal hernia. They had had their complaints for 2-18 years (median value 5,5 years), but apparently they had learnt to live with their pain. Twelve out of twenty stated that they tried to be cautious and avoid heavy lifts. Five men had been sicklisted during the last year, one had changed work due to back pain.

Their ages were 22 - 37 years (mean 32), heights 174 - 188 cm (mean 180) and all had a normal body weight (mean 76 kg).

Eight subjects had previously been treated by a physiotherapist individually or in group (so called Back school), including instructions in lifting technique and abdominal muscle training, but only one of them was still doing abdominal muscle exercises 2-3 times a week. Before our tests they were instructed in lifting techniques as regards leg lifting, so they all had roughly the same information.

METHODS

Assessment of trunk flexion strength (fig. 1).

Measurement of the strength of the trunk flexors was carried out in the upright position in the same manner as previously described (13).

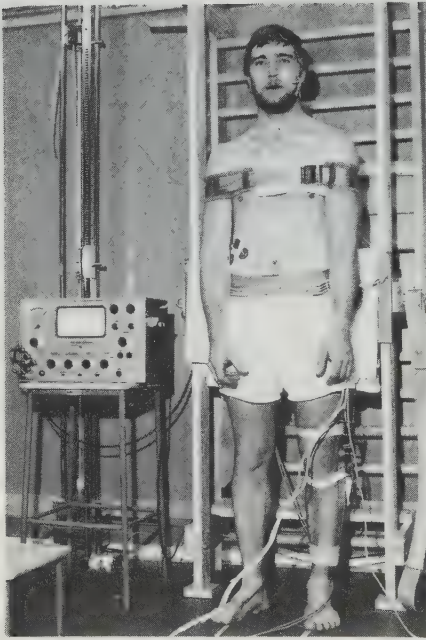


Fig. 1. Trunk muscle strength recording system. The strain-gauge is situated behind the subject. The figure also shows the catheter for IAP recording, the EMG electrodes over the right oblique abdominal muscles and the electrogoniometer on the left knee.

A special frame was made with a support behind the pelvis. A strap was placed across the chest and upper arms at the level of the attachment of the deltoid muscles. The tension in the strap was recorded by means of a strain-gauge. The recording system was calibrated daily and the test carefully standardized to be comparable before and after training. The position of the feet in relation to the frame was measured.

The subjects were told to do an attempted trunk flexion against the strap and not a hip flexion. A physiotherapist supervised the minute movements. The calculations of the bilateral motion axis previously reported (12) could then be applied also to this study. The axis lies about the intervertebral disc L3-4.

Recordings were made of three successive maximal contractions during at least 3 seconds. The estimates were then made from the median values.

Assessment of trunk extension strength

Measurement of the strength of the trunk extensors was performed with the same method, except that the subject faced the frame with the strap placed across the dorsal part of the chest and the upper arms at the same level as before.

Electromyographic recordings

The myoelectrical activities of the oblique abdominal muscles and of the erector spinae muscle were recorded with pairs of surface electrodes (disposable electrodes 3M Red Dot 2247 Ag/AgCl). The interelectrode distance was 5 cm. The skin was prepared in the prescribed manner with the enclosed piece of sandpaper and alcohol. The pairs of electrodes were placed - both on the right side - over the erector spinae at the level of the spinous processes L2 - L3 and over the oblique abdominal muscles at umbilical level and above the ventral iliac spine. The direction of the electrodes was parallel to the muscle fibres.

The electrodes were connected to pre-amplifiers fastened to the patient's waist and then by screened cables to amplifiers for subsequent tape-recording (Racal Store 14 FM) and visual control of the raw EMG on a mingograph (Mingograph 82 Siemens-Elema). The signals were full-wave rectified and integrated over a preset period, throughout this study 0,1 s.

The upper and lower cut-off frequencies were 1000 and 50 Hz respectively. An active T-filter with a slope of 12 dB/octave was used.

Intra-abdominal pressure recordings

The intra-abdominal pressure (i.e. intragastric) pressure was recorded via an open polyethylene catheter as previously described (13). The catheter was filled with isotonic saline and without a balloon. The subjects were not allowed to eat during the hours before the examination. After local anaesthesia by spray (Lidokain) three thin polyethylene catheters (Portex PP 100 with an internal diameter of 0,86 mm) were introduced through the nose to the upper part of the stomach. The pressure changes during respiration told us when the tip had passed the diaphragm and rested in the stomach. The distance between the tip of the catheter and the nostril was noted so that, at the examination after training, the catheter could be placed in the same position. The three catheters were fused distally. Only one was

open at the lower end and filled with saline for intraabdominal pressure recordings. The second one was used for intra-oesophageal pressure recording (to be reported elsewhere) and therefore plugged 25 cm proximally to the end. The third one also contained air distally and was intended only as a guide. By a three way stopcock the recording catheter was connected to a pressure transducer (Bentley Trantec) at the level of the iliac crest. The signals were transmitted to a pressure amplifier (BM Elektronik, Åhus, Sweden) for subsequent recording on magnetic tape. The pressure curves were continuously checked on the mingograph and the tube flushed with saline when necessary.

Before the examinations, the pressure recording system had been tested in a model and by X-ray during all movements that occurred as previously described (12). By continuously watching the pressure recordings, we could observe any interference such as blockage of the opening. From the X-ray we also calculated the source of error due to the external location of the transducer and corrected the pressure values accordingly.

The examination procedure

1. Recordings before and after training of the abdominal muscles.

Before and after abdominal muscle training the subjects were put through a standardized test programme where the strength of the trunk flexors and extensors was recorded and a series of lifts was carried out.

Lifts were done with 10, 25, and 40 kg, in all cases with three techniques, namely back lifting and two types of leg lifting. By back lifting is meant symmetric lifts with straight knees and bent back. The first mode of leg lift (leg lift A) is a symmetric lift with the feet placed behind the box, the knees flexed and the back as straight as possible. The second mode (leg lift B) was advocated by Davies (5) as "a new way to lift". The main point is that the feet have to be far enough apart to give a balanced distribution of the weight. The leading foot should point in the direction of the movement, the knees and hips should be bent and the back kept as straight as possible (fig. 2). The position of the feet makes it easier to keep the heels on the ground, while the leg lift A often forces you to balance on the forefeet. You can, moreover, come closer to the burden in leg lift B.

The lifts were performed from floor level to the upright position with the load on extended hanging arms in front of the body.

In all lifts, a specially made box was used (fig. 2). On the box there was an accelerometer for registration of vertical acceleration and a switch for recording lift-off and touch-down. Another switch was placed behind the subject at the Th 3-4 level when standing erect, recording the end of the lifting and the start of the lowering. The lifts were also controlled by an electrogoniometer on the left knee (fig. 1 + 2) and by videocamera recording.



Fig. 2. Leg lift B. For explanation see text.

Each subject could choose his own lifting speed and breathing technique, but otherwise the lifts were carefully standardized to facilitate comparisons between the recordings before and after training. The subject stood in fixed positions relative to the load and a physiotherapist gave instructions about the lifting technique to be used.

The subjects were asked to report any pain during or after a strength test or a lift. If they were afraid that the pain would prove too severe, that particular test or lift was excluded, to avoid all risks. The sub-

jects were allowed to rest between lifts.

Each lift was done twice and all calculations were made from the mean value of the two lifts. The order of lifts was changed between subjects. Each subject did, however, perform the lifts in the same order before and after training.

2. *Isometric training of the abdominal muscles*

The training to be evaluated was exactly the same as was previously performed by healthy subjects (12) except that, in back patients we had to consider their ability to endure the exercises and thus in some cases had to raise the load at the training more slowly.

During the five weeks the programme lasted, all subjects co-operated fully with our ambition to have the most intense and efficient training possible of the abdominal muscles. The subjects were not allowed to do any other physical training during that time.

Everyone had detailed personal instruction in the standardized technique to be followed and was checked twice a week throughout the period.

The initial position was supine, with hips and knees flexed, the heels supported, and with active plantar flexion of the feet. The back was pressed against the floor and the gluteal muscles were actively contracted. The training procedure was as follows: The subject breathed out and held his breath, after which he curled up until he experienced a maximal effort, though without changing the position of the pelvis. This posture was held for a pre-set time.

Each exercise was performed twice daily, with 10 curl ups on each occasion. The subjects kept records of the daily training. The load and holding time were raised successively by the physiotherapists. This was done both by extending the holding time by 15 seconds and by increasing the external torque through the position of the arms, as the subjects grew stronger. Two subjects had to be excluded from the training, one due to severe low back pain, and another due to intercurrent disease.

Evaluation procedure

The myoelectrical signals and the pressure recordings were stored on magnetic tape, together with the signals from the electrogoniometer and from the accelerometer and the two switches indicating the start and end of all liftings and lowerings. The analogue myoelectrical signals on the tape were fullwave rectified, and integrated over preset 0,1 s. periods, each containing 400 readings.

The pressure signals were averaged over the same periods from 0.5 s. before the lift-off to the end of the lifting and from the start of the lowering to 0.5 s. after the touch-down. The accelerometer recordings were treated in the same way.

STATISTICAL METHODS

The design of the study was chosen to get a matching situation where each subject could serve as his own control. This approach was considered essential on account of the great inter-individual variations in the variables studied.

In the strength tests, the calculations are based on the maximum activity during three consecutive 0,1 s. periods in the tested muscle and the activity of the other recorded muscle and the IAP read off for the same 0,3 seconds.

For the lifts the calculations are made from the peak IAP in the different types of lifts and from the average pressures and myoelectrical activities during the lifting and lowering respectively. As the time varied between the lifts, the time has been normalized and expressed as percentages of the whole time, and for lifting and lowering separately, it runs from 0 to 100%. The mean activity and mean pressure during the whole lifting and lowering procedure may then be compared (see fig. 4 + 6 + 9) before and after training. By calculating the 95% confidence limits of the mean difference between values before and after training, analysis of significance is carried out throughout the whole lifting procedure. In other respects, the analysis

of significance of differences was performed according to Student's t-test and the strength of covariance was determined by Pearson's correlation coefficient, r .

RESULTS

Trunk flexion strength

The muscle strength before and after training was compared in two ways:

1. *Measurement of the trunk flexors before and after training.*
Table I shows an average increase from 549 N to 671 N, that is 22% ($p < 0,0001$).

The maximum EMG activity of the oblique abdominal muscles was compared before and after training. One subject had to be excluded due to back pain, another owing to intercurrent disease and two more subjects because of technical interference. In the remaining sixteen there was a correlation between increase of strength and increase of activity ($r = 0,55$, $p = 0,014$).

2. *The load at training may be regarded as an indirect measure of the increase in muscle strength as the external torque and the holding time were increased with the improved capacity of each subject. Figure 3 shows that the subjects could perform heavier exercises after than before training.*

Table I. Trunk muscle strength (mean $\pm$ SD) before and after training. (N)

	Before	After	Diff	p
Trunk flexion strength n = 17	549 $\pm$ 114	671 $\pm$ 118	+22%	<0,0001
Trunk extension strength n = 16	837 $\pm$ 166	943 $\pm$ 123	+12%	<0,001

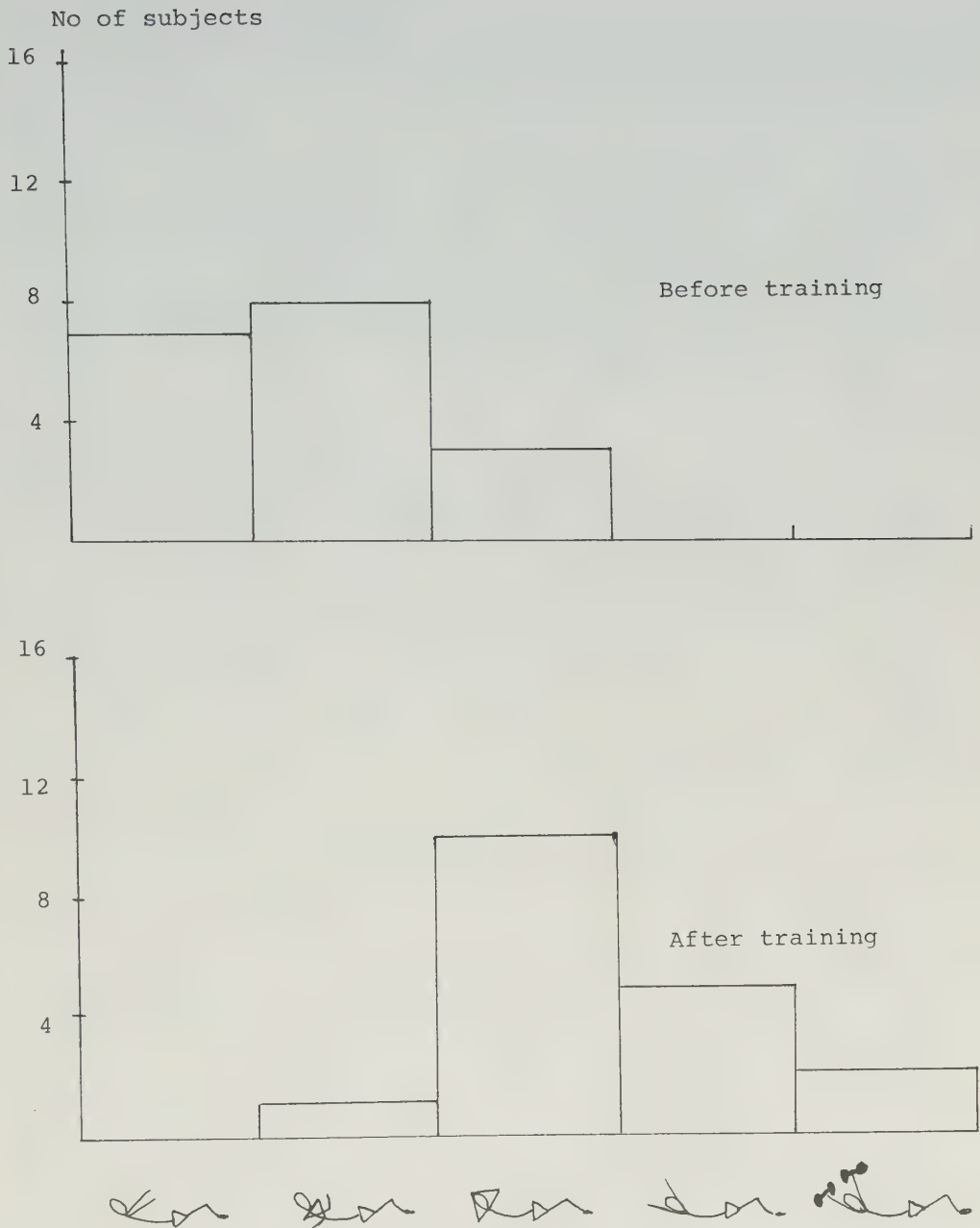


Fig. 3. The external torque could be successively increased during training ($n = 18$, for explanation see text).

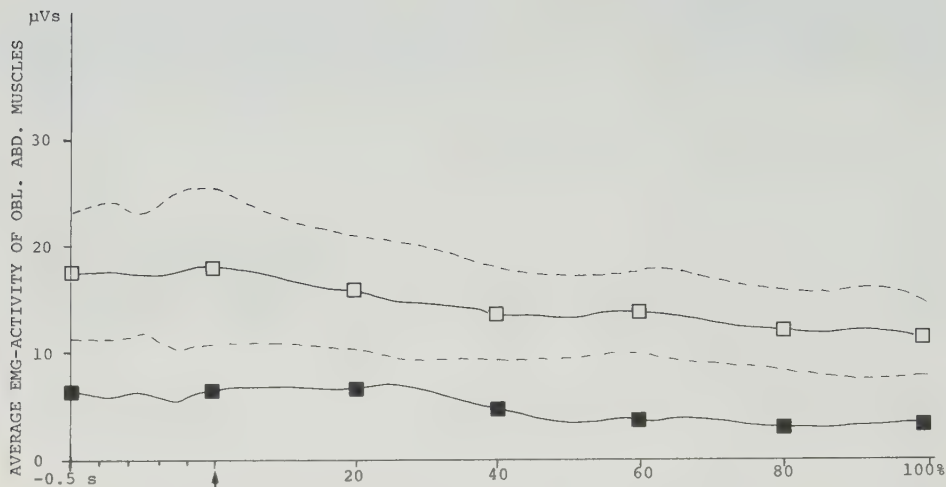


Fig. 4 a. EMG activity in the oblique abdominal muscles during lifting 10 kg leg lift A.

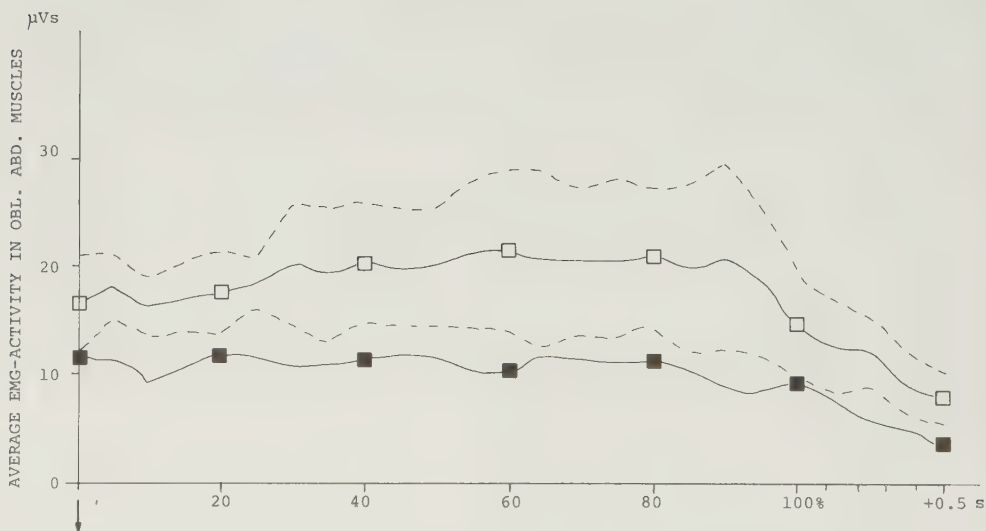


Fig. 4 b. EMG activity in the oblique abdominal muscles during lowering 40 kg leg lift B.

↑↓ describes start of lifting and lowering respectively.

□ — □ average activity before training with 95% confidence limits of the mean difference between values before and after training.

■ — ■ average activity after training.

For further explanation see text.

Trunk extension strength

Measurement of the trunk extensors before and after training. Table I shows an average increase from 837 N to 943 N, that is 12% ($p < 0,001$).

The maximum EMG activity of the erector spinae was compared before and after training. Four subjects had to be excluded due to back pain and another two for technical interference. The remaining fourteen showed no difference after training and no correlation between change in strength and change in activity.

Recordings during lifting

1. *The activity of the oblique abdominal muscles when lifting* was estimated during the whole working cycles, lifting as well as lowering. There was a constant decrease of activity after training, irrespective of lifting technique or load, which can be seen in practically all curves. The decrease is significant ($p < 0,05$) during 30-80% of the lifting time in back lifting, during 40-100% in leg lift A and 50-100% in leg lift B. The decrease is less pronounced during lowering but significant ($p < 0,05$) during 50-100% of the lowering time in leg lift B. Fig. 4 shows the oblique abdominal muscle activity in leg lift A with 10 kg (lifting) and leg lift B with 40 kg (lowering).

2. *The intra-abdominal pressure (IAP).*

The IAP curves are quite similar in shape in lifting as well as in lowering compared to those of the healthy subjects previously described (12). The curves vary between the patients, and in one patient between lifts with different weights, as regards the height of the peaks and their position in time, but the shape of the curves remain practically the same in all lifts of the same type.

The peak values of the IAP during lowering are, throughout, somewhat lower than the corresponding values during lifting, as for the healthy subjects (12).

Each subject performed all lifts twice. The average differences between these two lifts were 0.27 kPa with 10 kg, 0.47 kPa with 25 kg, and 0.66 kPa with 40 kg, or, for all lifts, 7.5%.

The IAP was compared before and after training (fig. 5, 6 and 7). It was then found that, in the whole material, there was no significant difference between lifts before and after training. This applies to all types of lifts, irrespective of lifting technique and load, in any 0.1 second phase of the lift, whether lifting or lowering. The average difference of peak values in the whole material is 0.09 kPa in lifting and 0.05 kPa in lowering.

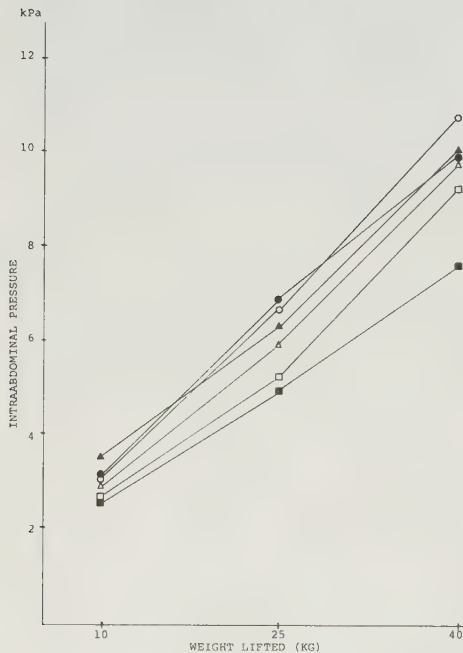


Fig. 5. Peak values of intra-abdominal pressure at lifting 10, 25, and 40 kg before and after training.

○ — ○ leg lift A before training ● — ● leg lift A after training
 □ — □ leg lift B before training ■ — ■ leg lift B after training
 △ — △ back lift before training ▲ — ▲ back lift after training

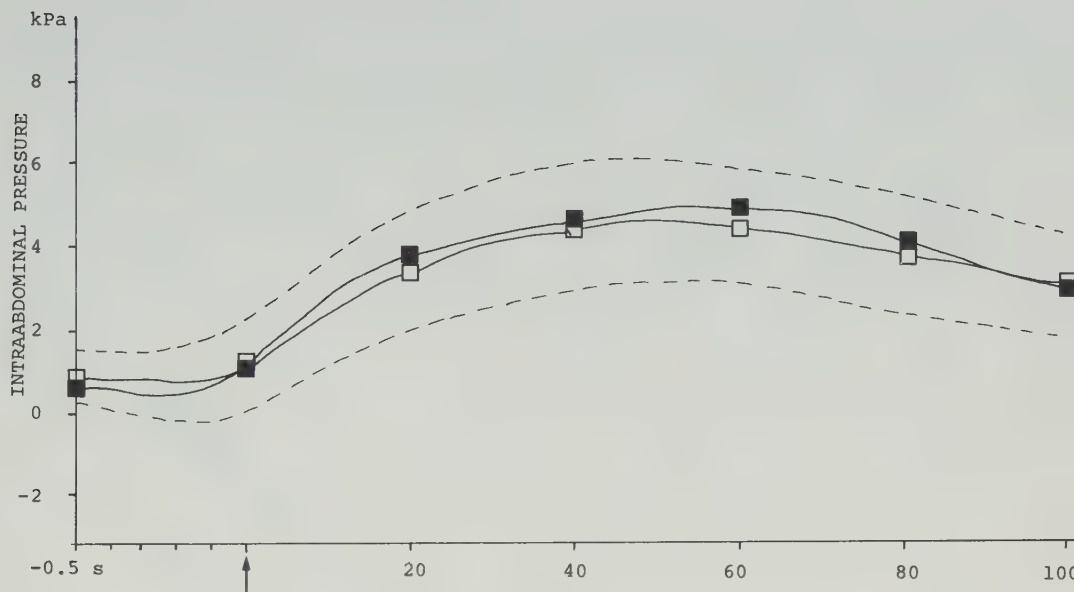


Fig. 6 a. Intraabdominal pressure during lifting 25 kg back lift.

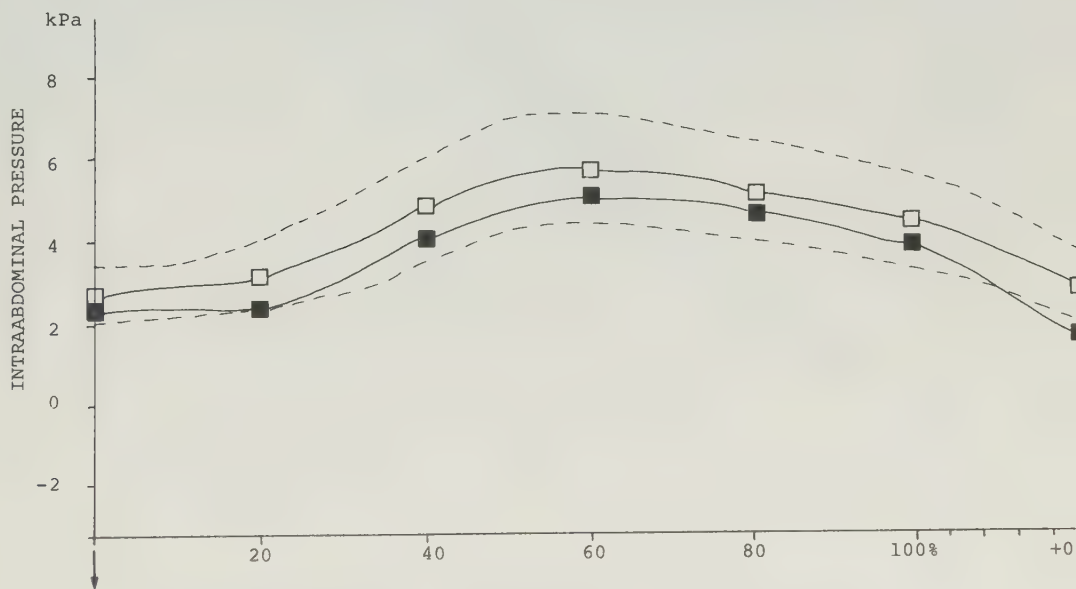


Fig. 6 b. Intraabdominal pressure during lowering 25 kg leg lift A.

↑ ↓ denotes start of lifting and lowering respectively.

□ — □ average IAP before training with 95% confidence limits of the mean difference between the values before and after training.

■ — ■ average IAP after training.

For further explanation see text.

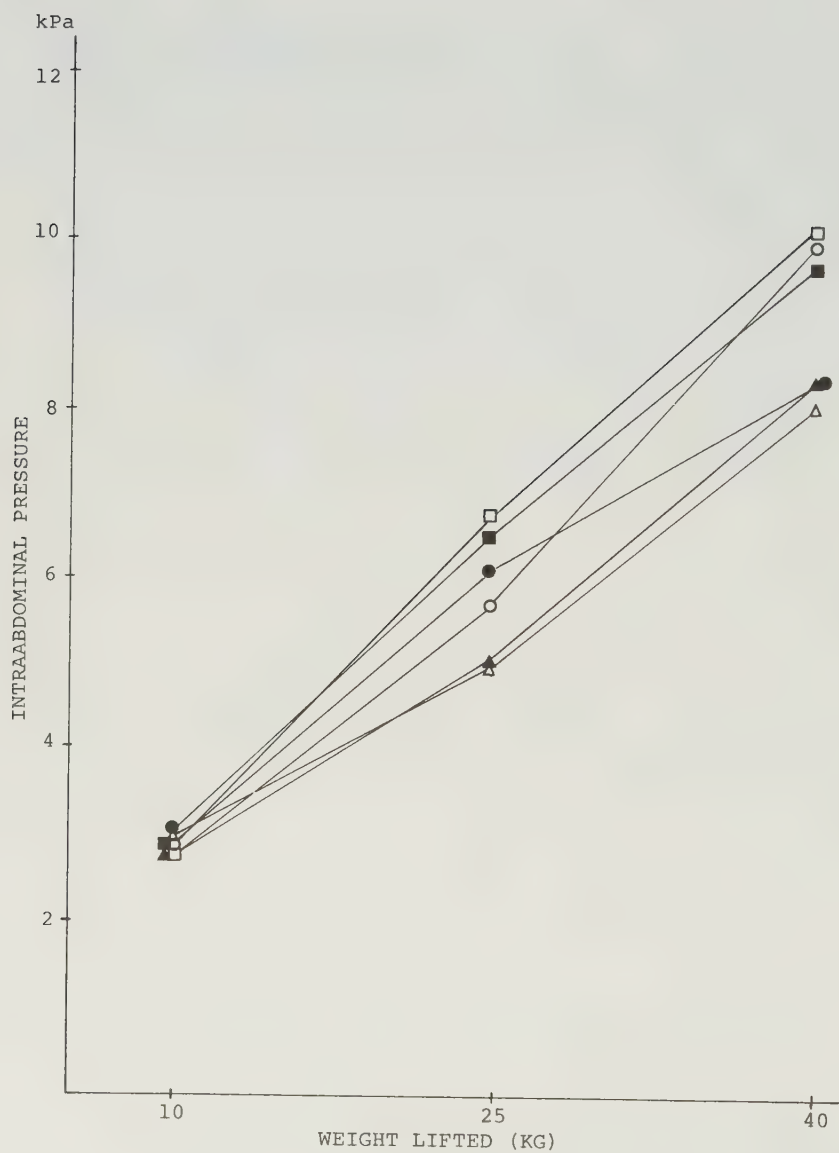


Fig. 7. Peak values of intra-abdominal pressure at lowering 10, 25, and 40 kg before and after training.

For explanation see fig. 5.

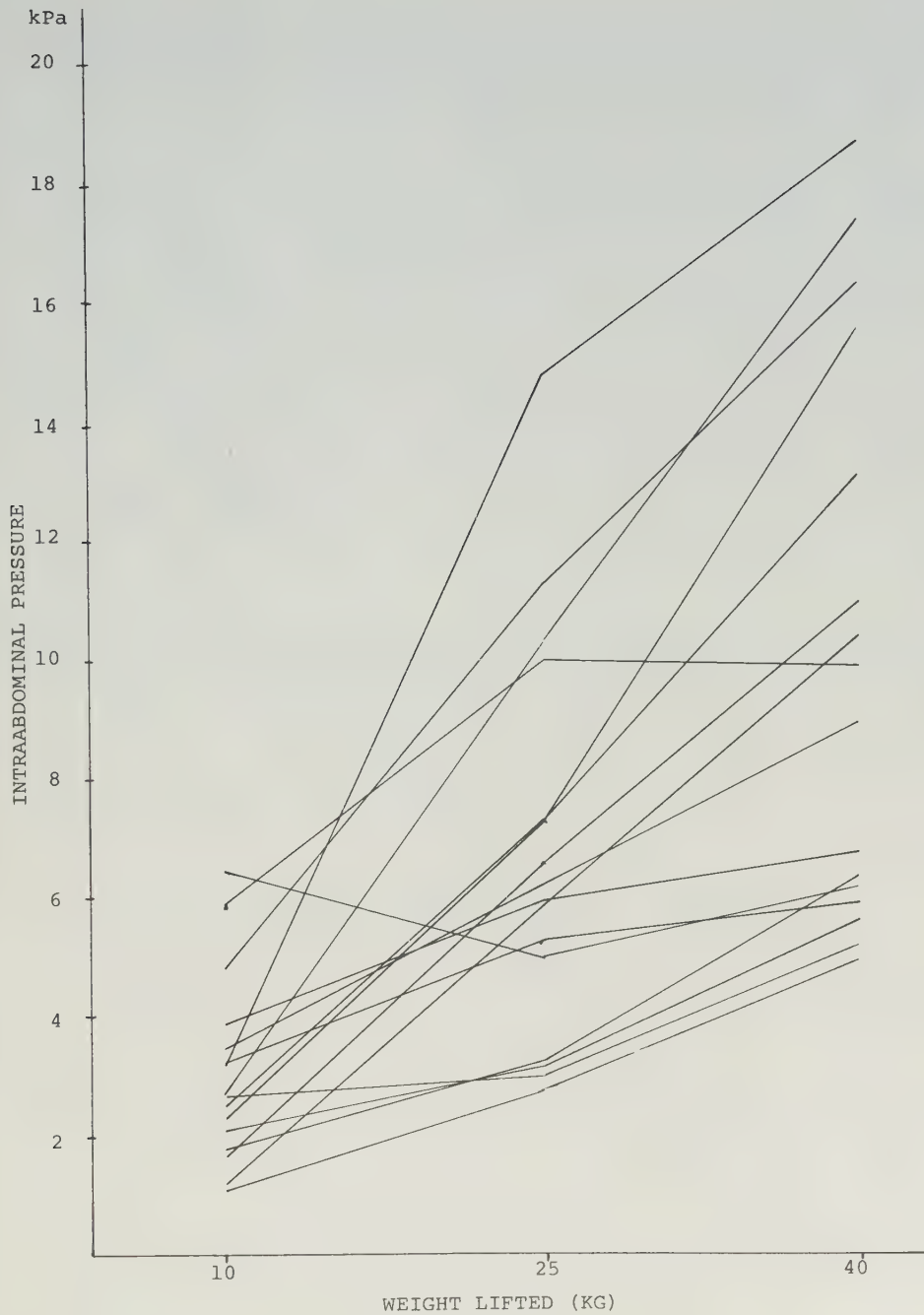


Fig. 8 a. Peak values of IAP at lifting 10, 25, and 40 kg, before and after training, back lift.

Each line represents one subject. The individual variations are considerable.

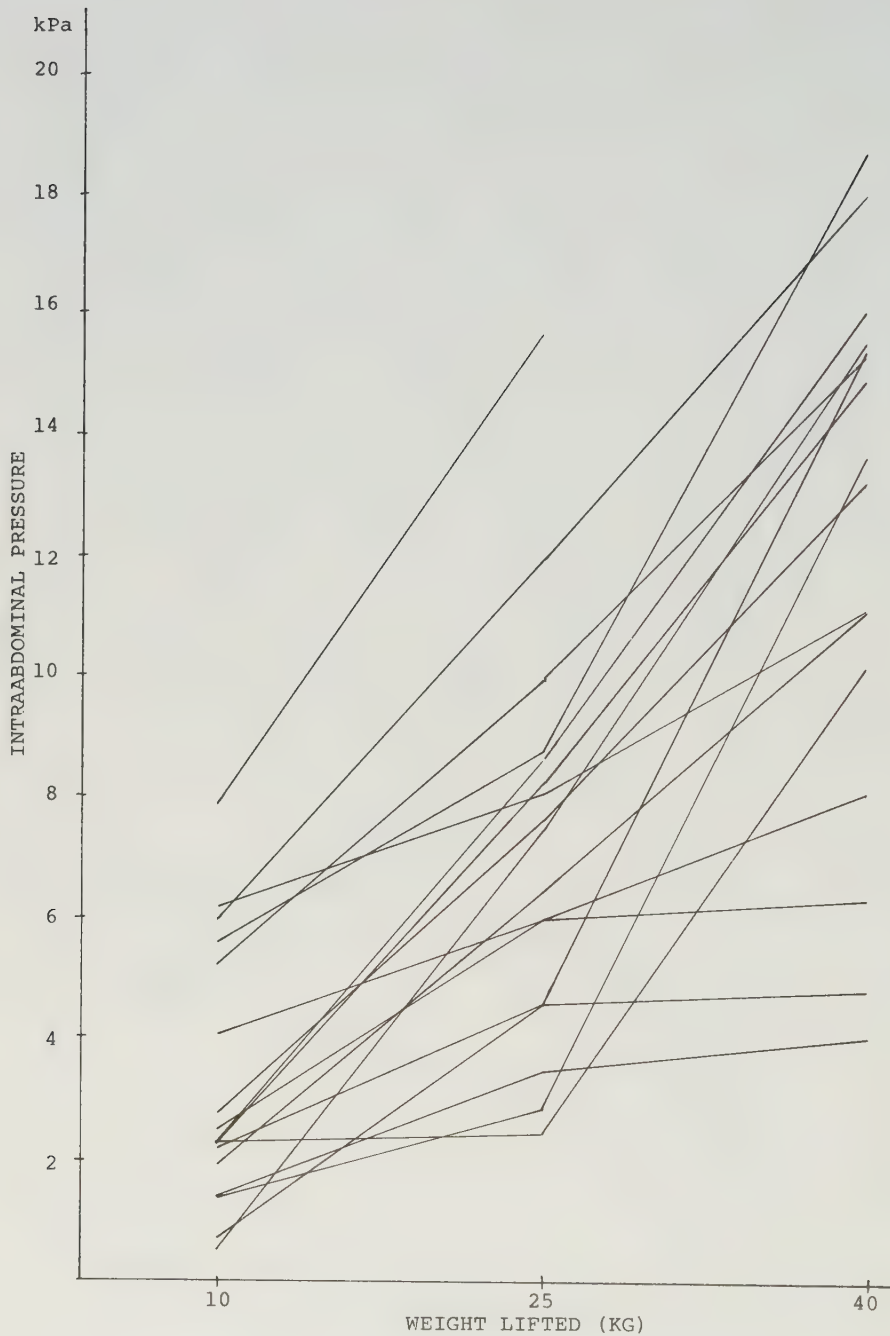


Fig. 8 b. Peak values of IAP at lifting 10, 25, and 40 kg, before and after training, leg lift A.

Each line represents one subject. The individual variations are considerable.

There were only small displacements of the IAP peaks after training. Thus, the peaks were displaced by 1-12% of the total time of lifting or lowering, i.e. up to 0.2 seconds.

In a few, individual cases, there were remarkable differences after training. One subject raised his peak IAP with 25 kg and 40 kg leg lift A and back lift up to 136% or 8.5 kPa, but not with leg lift B and not with 10 kg lifts. Two subjects reported pain during lifts after training. One of those raised his peak IAP considerably (by 69% or 5.7 kPa) but the other one lowered his corresponding peak IAP by as much (81% or 5.9 kPa). Apart from these, only a few lifts by another three subjects were reported painful. These lifts gave very inconsistent figures, and do not affect the average values.

The IAP when lifting varied considerably between the individuals (fig. 8 a + b). Back lifting of 25 kg could for instance produce an increase to between 2.6 and 14.8 kPa and leg lift A of 40 kg an increase to between 4.0 and 18.6 kPa. Leg lift B showed a corresponding variation.

We found no significant differences between the lifting technique as regards peak IAP or the average pressure during the whole time of lifting and lowering, though there was a tendency towards lower values during leg lift B with the heaviest loads (fig. 5).

3. *The relation between the activity of the oblique abdominal muscles and the IAP.*

If the activity of the oblique abdominal muscles is regarded as the cause of the increase of the IAP, there should be a relation between the two both in time and quantity when comparing the lifts before and after training.

The time intervals between the maximum activity of the oblique abdominal muscles and the maximum of the IAP vary between 0.0 and 0.6 s. at leg lifts A and B and between

0.9 and 1.6 s. at back lifts. The isometric training did not affect these relations in time.

The coefficient of correlation was calculated between, on the one hand, the change of activity of the oblique abdominal muscles and, on the other hand, the change in the IAP before and after training in each individual (table II). We found no positive correlation between the two variables, except at one instance (leg lift B with 40 kg). We might thus conclude that an increase or decrease of the activity of the oblique abdominal muscles did not generally result in a rise or fall respectively of the IAP.

Table II. Relation between change of oblique abdominal muscle activity and change of intraabdominal pressure after training.

Technique	Weight	Average change		r	p
		EMG (uVs)	IAP (kPa)		
Leg lift A	10	-5.5	+0.41	-0.45	0.036
	25	-5.6	+0.65	+0.17	NS
	40	-10.4	-0.49	+0.29	NS
Leg lift B	10	-9.9	+0.11	-0.11	NS
	25	-3.2	+0.21	+0.01	NS
	40	-6.1	-1.4	+0.57	0.010
Back lift	10	-5.3	+0.55	+0.24	NS
	25	-4.8	+0.36	+0.05	NS
	40	-5.2	+0.45	+0.27	NS

4. *The activity of the erector spinae muscle.*

The myoelectrical activity of the erector spinae muscle rose with increased weights during lifting. The same pattern was seen during lowering, though the differences were not significant between lifts with 10 and 25 kg.

There was no difference in the erector spinae activity after

training. That applies to each type of lift, irrespective of technique and load and was seen in practically all 0.1 second phases of lifting and lowering (fig. 9).

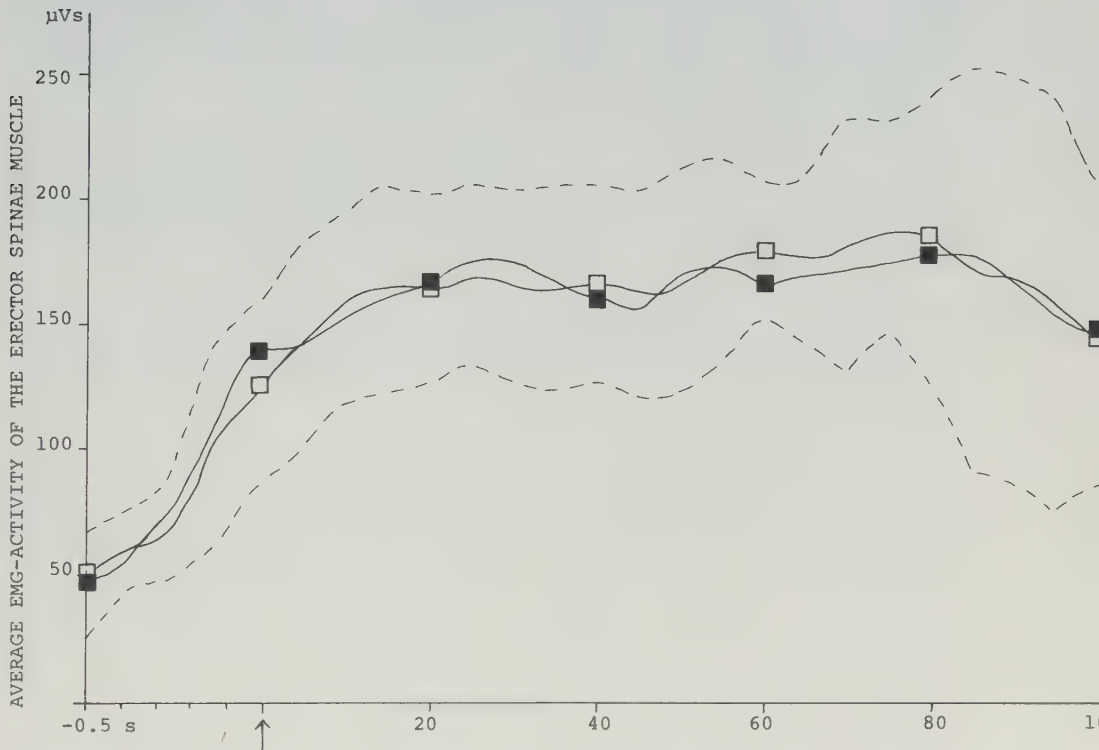


Fig. 9. EMG activity in the erector spinae muscle during a) leg lift A 40 kg lifting, and b) leg lift B 40 kg lowering.
For explanation see fig. 4.

5. *Lifting time and patterns of movement.*

The average lifting times for the different techniques and loads were 1.7 - 2.0 s. before training and 1.4 - 1.7 s. after training. The corresponding values of lowering were 1.9 - 2.2 s. before versus 1.5 - 1.9 s. after training. This corresponded to an average reduction of 17% in lifting as well as lowering.

There was no systematic differences between the various lifting techniques or loads, but for the finding that the lifts

with 40 kg lasted 0.1 - 0.2 s. longer than the lifts with 10 and 25 kg.

By recording the knee angle during lifting before and after training, we found that the lifts in this respect were performed in the same way after training.

The general patterns of movement as judged from the average curves of activity and IAP showed very small differences after training, apart from the constant reduction in oblique abdominal muscle activity. The only change observed was somewhat smaller confidence limits of some variables in certain types of lifts, denoting a smaller inter-individual variation.

The tested techniques of lifting (back lift, leg lift A, leg lift B) presented, of course, different patterns of movement. This difference applies to back lifts versus leg lifts, while the two leg lifts were rather similar in our variables. The most important features of back lifts and leg lifts have been described previously for healthy subjects (12) and in relation to low back patients (13) and it should only be mentioned here, that those findings were not affected by the training of the low back patients.

DISCUSSION

Previous studies showed no effect of abdominal muscle training on IAP during lifting (12,17) and no increase of oblique abdominal muscle activity after training but a decrease (12). Subjects with low back pain might, however, react differently on training, as they, according to some investigations (e.g. 1, 20, 21), may have reduced abdominal muscle strength. They might also have another pattern of movement with another response to muscular training. It therefore seemed necessary to study the effect of training on subjects with low back pain as well.

Our subjects were a selected group. Strictly speaking, they were not patients, i.e. under medical care at the time, but yet suffering from chronic low back complaints since, on the average, more than five years. Their pains grew worse with increased lumbar load. In other words, they were expected to benefit from unloading the lumbar spine and were thus candidates for abdominal muscle training. Moreover, they were interested in working full time and also relatively inactive in leisure, and so they were supposed to do the exercises with energy, and to produce a great increase in muscular power. This was considered important when evaluating a training programme on subjects with pain.

The training programme

There are several techniques for training the abdominal muscles. For evaluation we selected one method that is commonly used and has been shown to activate the external oblique muscles (i.a. 27, 9, 10, 11, 6, 22) and the internal oblique muscles (27), beyond the rectus abdominis muscles. There are, so far, no study on the activation of the transverse abdominal muscles.

According to Halpern & Bleck (11), our training procedure with curl-ups produces activity during 90% of the isotonic phases compared to 20-40% in the sit-ups. Ekholm et al (6) compared the activity during the isometric phase of various curl-ups

and two purely isometric exercises and concluded that the supine hook-lying curl up, as used in this study, elicited about the same activity (in percentage of maximum test) as the other methods except curl-ups with simultaneous trunk rotation which produced somewhat more activity.

Our subjects had to curl up until maximal effort and not until a specified angle between the trunk and the floor. This was supposed to increase the activity, according to a previous pilot study. The pelvis was not allowed to move. Simultaneous activation of the plantar-flexors of the ankle did not affect the activity of the abdominal muscles, whether as increase or decrease (6). This element in our training programme was introduced to inhibit the psoas major muscle, according to Janda (16), but needs further study (6).

The subjects were told to press the back against the floor and to contract the gluteal muscles, in order to stabilize the pelvis by a posterior pelvic tilt and perhaps to inhibit the iliopsoas muscle and the other hip flexors. From many records during training we found that the erector spinae muscles were mostly not or sometimes slightly activated in purely symmetric curl-ups. This agrees with Blackburn and Portney (2), who reported very slight activity in the paraspinal musculature on the Th 6, L 3 and S 1 levels during curl-ups after posterior pelvic tilt (2-5% of maximum activity).

Ricci et al (22) states that curl-ups and sit-ups, whether from a long-lying or a hook-lying position, start with an anterior pelvic tilt, hyperlordosis of the lumbar spine and hyperextension of the upper trunk. In response to pelvic rotation, the abdominal muscles should start the curl-up with an eccentric contraction, followed by a concentric and finally an isometric contraction. As for the gluteal activation when starting and the minimum of erector spinae activity when training, we may assume that our subjects mostly performed training with concentric and isometric contractions.

In summary, we may conclude that our group trained their oblique abdominal muscles with one of the most efficient isometric training methods available (except for curl ups with trunk rotation).

The training period was five weeks which should suffice for evaluating the gain of training (14).

Trunk flexion strength

The biomechanics of our test procedure were discussed previously (12). The bilateral axis of motion was found to be located about the intervertebral disc L 3-4. In this context it should be pointed out that we by the strain gauge in trunk flexion test measured the net effect of the anterior abdominal muscles minus the extending moment of the IAP and the simultaneously activated antagonists, i.e. the erector spinae muscles. The average IAP when recording the strength increased from 11.7 kPa (SD = 4.3) to 16.7 kPa (SD = 6.2) after training. The average activity of the erector spinae muscle was 14.1% before and 13.1% after training out of its maximum activity during the trunk extension strength test. (This activity was unchanged despite increased strength values). These figures seem to show that the anterior abdominal muscles (the rectus abdominis, the ventral part of the external oblique and most of the internal oblique) had to overcome greater forces after training and thus had become even stronger than shown by the instrument. The significant positive correlation between change of strength and change of EMG activity in the oblique abdominal muscles demonstrates that the latter muscles partly account for the increased flexor strength, and also indicates that the training has resulted in an improved recruitment of motor units.

The psoas major muscle, if trained at all, should exert a rather small forward bending moment (1) or no such moment at all (8).

The increase of values during strength tests may be due to augmented strength but also to an enhanced skill in the per-

formance of the strength test, a "motor learning" (15, 23, 26). According to Hood et al and Schenk et al repeated tests of knee extension strength gave significant increases between the first three weekly tests, after which the increases became less but yet considerable for the five weeks' period as a whole (15, 23). Tornvall studied trunk flexion and trunk extension without other training during altogether 60 tests for 2 1/2 months and could find a great rise in test values (26). He noted that this rise was first manifest after 6-7 examinations. The question also arises if this frequent testing in reality meant training besides testing.

When they were familiar with the equipment our subjects were asked to do three maximum strength tests and then, after five weeks, another three tests. It thus appears that the tests after training reflect mainly the effect of training. This opinion is supported by the fact that the load at training could be increased successively (fig. 3).

Trunk extension strength

The biomechanics of trunk extension test were previously discussed (12, 13). The bilateral motion axis was found to be located ventrally to the L 1 - L 2-segment. The rectus abdominis muscles are - according to studies by Carlsöö (4) in healthy subjects - only occasionally and then only slightly activated during the test. Activation of the oblique abdominal muscles during trunk extension strength test was not changed significantly after training. It thus seems improbable that the flexing moment due to these muscles was reduced during the extension test.

The average IAP during the trunk extension test was 16.0 kPa (SD = 4.1) before and 20.2 kPa (SD = 6.2) (= +26%) after training, but the extending moment of IAP is probably rather small, due to the location of the motion axis.

Our subjects activated their erector spinae muscles very slightly, if at all, during the training. Even if they omitted

the posterior pelvic tilt, the erector spinae activity would not exceed 8-12% of maximum activity, according to Blackburn et al (2). It thus seems unlikely that the training should cause any notable increase of back muscle strength. This is congruous with the lack of rise in EMG activity and the lack of correlation between change in strength and change in activity.

It thus remains to explain the observed increase in trunk extension strength (+12%). It may be caused by technical faults due to variable positions of the trunk, shown to be very important from isokinetic measurings of back muscle strength (25). In addition the rise in IAP might have influenced the test results.

Trunk flexion strength and trunk extension strength increased independently from each other. Those subjects who gained most in flexion might gain less in extension and vice versa. The average extension/flexion - ratio was reduced from 1.54 to 1.40, as expected.

Recordings during lifting

The most interesting approach when studying effects of training is not to look for the results in strength tests but to find out, how the subjects make use of their increased capacity in daily life activities. We chose to study lifts, as they are common in the construction industry, as they expose the low back to considerable loads and, finally, as they are possible to standardize fairly well.

We have previously reported (13) that these subjects with low back pain had weaker abdominal muscles than another comparable group of healthy subjects. It should therefore be interesting to find out if they took advantage of their newly acquired ability of recruiting more motor units than before training.

The myoelectrical activity of the oblique abdominal muscles was, however, constantly reduced after training, irrespective

of lifting techniques or weights of the burden. This implies that they utilized the metabolic effects of training on the muscle cells, so that a given muscular work could be performed with less motor units. The improved ability to recruit more motor units was, however, not used during lifting. This result agrees completely with our previous study on healthy subjects (12).

As for the healthy subjects, we could find no correlation between, on the one hand, the change of oblique abdominal muscle activity and, on the other hand, the change of IAP after training.

Furthermore, we could find no correlation between abdominal muscle strength and IAP at lifting (13). Subjects with and without low back complaints produced the same IAP in lifting despite marked differences in abdominal muscle strength.

Against this background it is not surprising that our subjects with low back complaints did not generally change their IAP when lifting though they had trained isometric curl-ups intensively for five weeks. This agrees with our previous study in healthy subjects (12) and with Legg (17), who also trained healthy subjects but with another method (dynamic sit-ups).

Pain may influence muscle strength tests and IAP at lifting as well (7). In this study the painful strength tests were excluded and the few lifts with reported pain gave so inconsistent values that, on the whole, the influence of pain can be disregarded.

A great difference was found between the individuals as regards peak IAP during lifting, as it was for the healthy subjects (12). This cannot be explained by variations in levers of the load or body weight but needs further study.

The activity of the erector spinae muscles was quite unaffected by the training. It was anticipated that the activity of

the erector spinae muscles would be reduced in case of increased IAP and vice versa, a phenomenon which was found in some instances in the two subjects who showed a marked increase of IAP after training. But, on the whole, the average activity is markedly unchanged throughout the lifts (fig. 9).

During lifting a rather slight activity of the abdominal muscles is required (13). Strengthening of these muscles seemed to have no effect during lifting and the pattern of activation was unaffected by the training. In contrast to this lack of effect on the IAP during lifting, there was a marked increase of IAP during the maximum strength tests. This implies that during maximal contractions an increase in muscle strength also gives an increase in IAP.

The IAP seems to be rather important in reducing the load on the lumbar spine. Schultz et al (24) and Broberg (3) have, from different measurements, calculated the relief of compression on the spine to be from 4 to 30 per cent and from 5 to 30 per cent respectively (compared to zero pressure). The two determinations were made on static situations but yet tell us something about the magnitude of the relief. In addition, we need calculations on the effect of IAP in dynamic situations. It should, furthermore, be pointed out that there is a "force balance" (3) between the abdominal muscles and the IAP, and that, accordingly, the IAP is necessary for the muscular stabilization of the trunk.

Conclusion

In this and in a previous study on twenty healthy subjects and twenty subjects with chronic low back pain, we found that intense isometric abdominal muscle training did not generally affect the intraabdominal pressure during lifting. Moreover, there seemed to be convincing evidence that during lifting the oblique abdominal muscles are of minor importance for the IAP. The lack of effect of training could be due to this finding and to the facts that the pattern of movement at training is quite different from that at lifting, and that the training does

not affect the mechanisms responsible for the IAP during lifting. Further studies are needed to elucidate these mechanisms.

ACKNOWLEDGMENT

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Lumbar Spinal Support and Weightlifter's Belt – Effect on Intraabdominal and Intrathoracic Pressure and Trunk Muscle Activity during Lifting.

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INTRODUCTION

Clinical observations indicate that a weightlifter's belt can relieve low back pain in certain instances and that it may also prevent low back pain in workers with frequent heavy lifts (6). There are some studies on the effects of lumbar spinal supports in different situations, such as trunk muscle activity, intraabdominal and intrathoracic pressure in rest and in static loadings (10), intradiscal pressure in standing (12), trunk muscle activity in standing at rest and in walking (14) and intraabdominal pressure at different activities (2). The effects of a weightlifter's belt on the trunk muscle activities and intratruncal pressures are, however, unknown but should be clarified, before we can recommend common use of belts as prevention. For this reason it is most important to determine if a belt causes a reduced muscular response to load or not.

The aim of this study was to study the effect of two types of belts on the activity of the oblique abdominal muscles and the erector spinae muscle, and on the intraabdominal and intrathoracic pressure during lifting. The two belts were the common weightlifter's leather belt and a specially made belt of plastic with an extended abdominal support.

MATERIAL (Table I)

Twenty subjects from the construction industry with chronic low back pain and ten well-trained weightlifters took part in the investigation.

The subjects with low back complaints, previously described (3), were picked out from the unions' lists of members and our previous case records from the medical health service for all construction workers in the city of Malmö. They all reported more or less continuous lumbar pain without sciatica for 2-18 years (median value 5.5 years) with an aggravation by heavy work or by protracted static posture. On examination we found local

tenderness and suspected instability in the lumbosacral and/or the adjacent lumbar segments, while the thoracic spine, sacroiliac, hip and other joints and routine tests were quite normal in all cases. None had a suspected inguinal hernia.

They were all working full time, only five of them had been sicklisted during the last year. One had changed work due to back pain.

Table I. Characteristics of the low back patients and the weightlifters.

	Low back patients	Weightlifters
Number	20	10
Age (years) mean	32	23
range	22 - 37	18 - 28
Height (m) mean	1.80	1.74
range	1.74 - 1.88	1.61 - 1.88
Weight (kg) mean	76	80
range	57 - 89	58 - 123
Duration of low back pain (years) median	5.5	*
range	2 - 18	
Duration of weight lifting (years) median	-	6.5
range		2 - 12

*) see text.

The ten weightlifters were picked out from the "Baltic Club", a weightlifters' club in the city of Malmö. They were all very skilled in the technique of weightlifting and had been training for 2-12 years (median value 6.5 years). Three of them were national champions in their respective weight classes.

Three weightlifters reported previous minor low back complaints of short duration and two had had intermittent low back pain for 1-3 years but not during the last year. Only one subject had slight pain during the study, though he was still able to train and work.

One of the patients had been using a corset in leisure time for six years, and another a weightlifter's belt for six months. All the weightlifters generally used leather belts for the heaviest training and at competitions.

METHODS

The lumbar spinal support and weightlifter's belt (Fig. 1 a).

A specially designed support was made of flexible, non-elastic syrlon, a thermoplastic material, 2 mm in thickness, with holes for the screened cables from the electrodes (Gert Karlsson, Camp Scandinavia AB). The support was supplied with an extended anterior section and given a shape to fit in with the low back and with the interspace between the lateral costal arch and the iliac crest (fig. 1 b). The support, made in three sizes, consisted of two parts joined together by strings and clasps. The subjects were asked to tighten the support firmly but yet comfortably enough to be used all day at work. The strings were graded and each subject performed all lifts with the same tightness.

The weightlifter's belt was made of leather, 3 mm in thickness somewhat broadened dorsally but on the whole narrower than the other support, especially anteriorly. It was made in three sizes and the subjects were also here asked to tighten the belt in the same manner and then to keep it unchanged during all lifts with the belt.

Electromyographic recordings

The myoelectrical activities of the oblique abdominal muscles and of the erector spinae muscle were recorded with pairs of surface electrodes (disposable electrodes 3M Red Dot 2247 Ag/AgCl). The interelectrode distance was 5 cm. The skin was prepared in the prescribed manner with the enclosed piece of sandpaper and alcohol. The pairs of electrodes were placed - both on the right side - over the erector spinae at the level of the spinous processes L2-L3 and over the oblique abdominal muscles at umbilical level

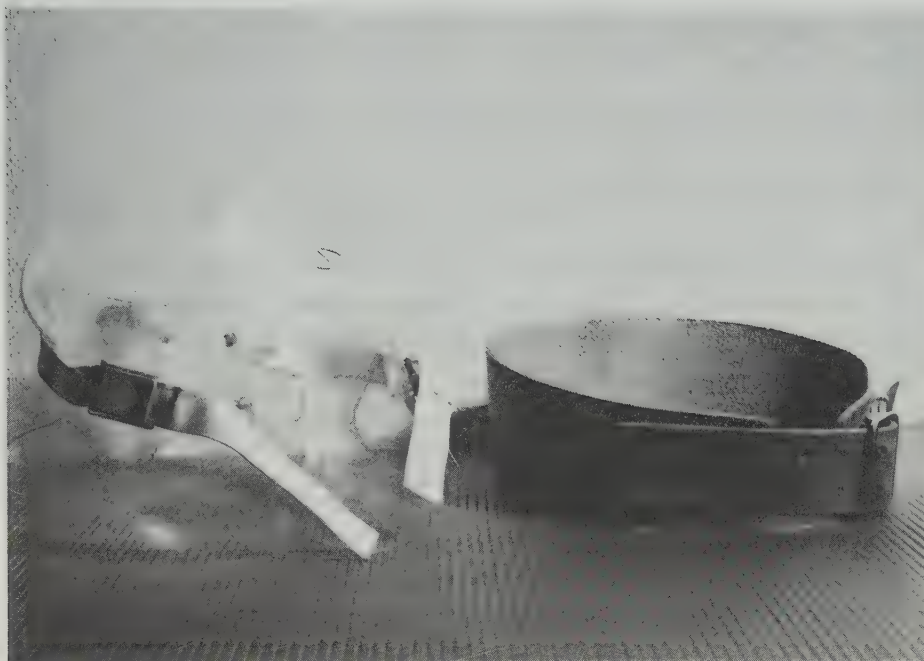


Fig. 1 a. The lumbar spinal support of syrlon (left), and the weightlifter's belt of leather (right).

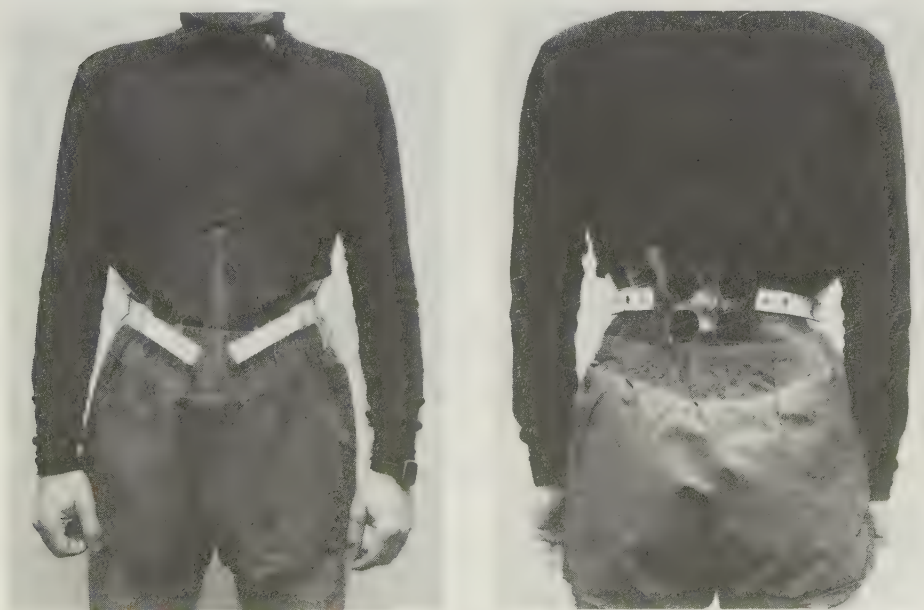


Fig. 1 b. The support of syrlon on a subject. Note the holes for the screened cables from the electrodes and the extended anterior section.

and above the ventral iliac spine.

The direction of the electrodes was parallel to the muscle fibres.

The electrodes were connected to preamplifiers at the subject's waist outside the belt or support. The signals were then transmitted to amplifiers for subsequent tape recording (Racal Store 14FM) and visual control of the raw EMG on a mingograph (Mingograph 82 Siemens-Elema). The upper and lower cut-off frequencies were 1000 and 50 Hz respectively. An active T-filter with a slope of 12 dB/Octave was used.

Intraabdominal and intrathoracic pressure recordings

The intra-abdominal (i.e. intragastric) and the intrathoracic (i.e. intra-oesophageal) pressures were recorded via an open polyethylene catheter as previously described (3). The subjects were not allowed to eat during the hours before the examination. After local anaesthesia by spray (Lidokain) three thin polyethylene catheters (Portex PP 100 with an internal diameter of 0.86 mm), fused distally, were introduced through the nose to the upper part of the stomach. The pressure changes during respiration told us when the tip had passed the diaphragm and rested in the stomach. One of the catheters was open at the lower end and filled with saline for intraabdominal pressure recordings. The second one was supplied with an opening 25 cm proximally to the end, plugged distally from the opening, and filled with saline for intrathoracic pressure recordings. The third one contained air and was only intended as a guide. By three way stopcocks the recording catheters were connected to pressure transducers (Bentley Trantec) at the level of the iliac crest. The signals were transmitted to a pressure amplifier (BM Elektronik, Åhus, Sweden) for subsequent recording on magnetic tape. The pressure curves were continuously checked on the mingograph and the catheters flushed with saline when necessary.

The pressure recording system was previously tested in a model and by X-ray during all movements that occurred (4). From the X-ray we calculated the source of error due to the external location of the transducer and corrected the pressure values accordingly.

The examination procedure

The subjects were asked to perform a series of standardized symmetrical

lifts without any support and with one of the two supports in the patient group and with both in the weightlifter group. Table II shows the programme for the two groups. Lifts were done with two techniques, namely back lifting and leg lifting. By "back lifting" was meant symmetric lifts with straight knees and bent back. "Leg lifting" was used for lifting with bent knees and the back as straight as possible.

Table II. Lifts performed by the low back patients (P) and by the weightlifters (WL).

Technique	Weight (Kg)	Without any support	With support of syrlon	With weight- lifter's belt
Back lifting	0	P	P	
	10	P	P	
	25	P	P	
Leg lifting	0	P	P	
	10	P	P	
	25	P	P	
	55	WL	WL	WL

The lifts were performed from floor level to the upright position with the load on extended hanging arms in front of the body.

In all lifts a specially made box was used, 40 x 25 x 16 cm, which could be symmetrically loaded with an appropriate number of 5 kg weights. To the box was attached a switch for recording lift-off and touch-down. Another switch was placed behind the subject at the Th3-4 level when standing erect, recording the end of the lifting and the start of the lowering. The lifts were also controlled by an electrogoniometer on the left knee.

The subjects could choose his own pace and breathing technique but otherwise the lifts were carefully standardized to facilitate comparisons between recordings with and without the different supports. The subject stood in a fixed position relative to the load and a physiotherapist gave instructions about the lifting technique to be used.

The subjects were asked to report any pain during the lifts. If they were afraid that the pain would prove too severe, that particular lift was excluded to avoid all risks. The subjects were allowed to rest between the lifts.

Altogether, our patient group performed 200 lifts with the lumbar spinal support of syrlon and 200 comparable lifts without any support. The weightlifters did, in total, 20 lifts with the support of syrlon, 20 lifts with the weightlifter's belt and 20 comparable lifts without any support.

Evaluation procedure

The myoelectrical signals and the pressure recordings were stored on magnetic tape, together with the signals from the electrogoniometer and the two switches indicating the start and end of all liftings and lowerings.

The analogue myoelectrical signals on the tape were fullwave rectified and integrated over preset 0.1 s. periods, each containing 400 readings. The signals from the pressure transducers were averaged over the same periods from 0.5 s. before the lift-off to the end of the lifting and from the start of the lowering to 0.5 s. after the touch-down. The electrogoniometer recordings were treated in the same way.

For technical reasons it was impossible to evaluate the effects of the support on the lowerings done by the weightlifters.

STATISTICAL METHODS

The design of the study was chosen to get a matching situation, where each subject could serve as his own control. This approach was considered essential on account of the great variations in the variables studied. Each type of lift was done twice and all calculations were made from the mean value of the two lifts.

The average myoelectrical activities and the average pressures with and without a support were determined during the whole working cycle, lifting as well as lowering. As the time varied between the lifts, the time was normalized and expressed as per-

centages of the whole time, and, for lifting and lowering separately, it runs from 0 to 100%. By calculating the 95% confidence limits of the mean difference between values with and without a support, analysis of significance was carried out throughout the whole lifting procedure.

RESULTS

Fig. 2 a-d and 3 a-d illustrate the differences by lifting with and without a support in two instances, namely leg lifting 25 kg by the patients and leg lifting 55 kg by the weightlifters.

1. The myoelectrical activity of the oblique abdominal muscles was quite unaffected by the supports. This applies to all types of lifting, whether by patients or weightlifters. Neither was there any difference if the weightlifters wore the lumbar support of syrlon or the weightlifter's belt of leather.

As for the lowering the myoelectrical activity of the patients was also quite unaffected by the support. The values of the weightlifters were impossible to evaluate, as previously mentioned.

2. The myoelectrical activity of the erector spinae muscle showed a significant increase of activity during the whole lowering at back lift 25 kg with a lumbar support but was otherwise quite unaffected throughout all lifts and lowerings, irrespective of technique or weights, whether done by low back patients or weightlifters, with a lumbar support or a weightlifter's belt.
3. The intraabdominal pressure rose uniformly throughout all lifts. For the support of syrlon the average increases were 1.0 - 2.5 kPa during the whole lifting and lowering, irrespective of the lifting technique and the weight of the burden. For the belt, the average increases were 2.3 - 3.0 kPa

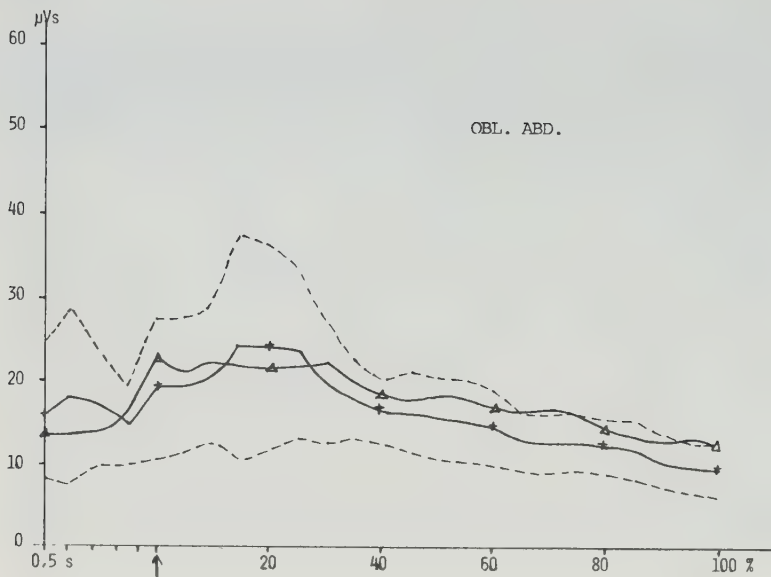


Fig. 2 a.

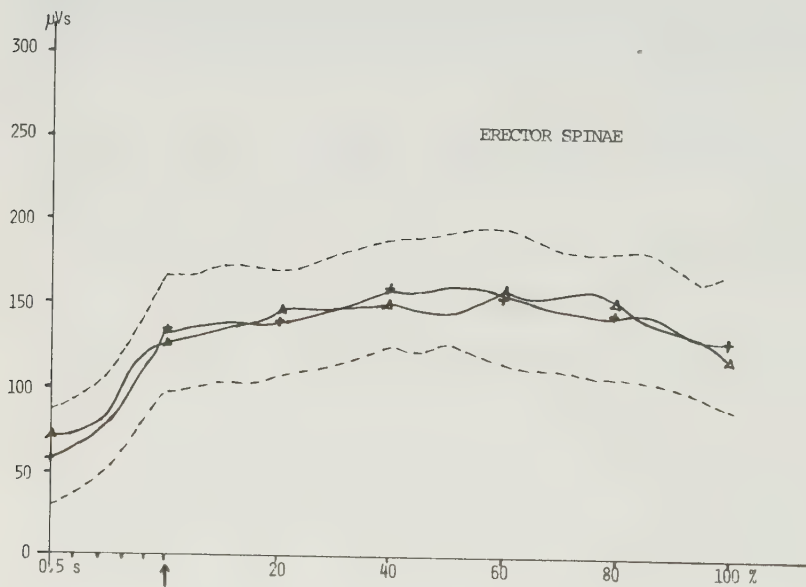


Fig. 2 b. Leg lifting 25 kg by low back patients with and without a support of syrlon.

- a) The oblique abdominal muscles.
- b) The erector spinae muscle
- c) The intraabdominal pressure.
- d) The intrathoracic pressure.

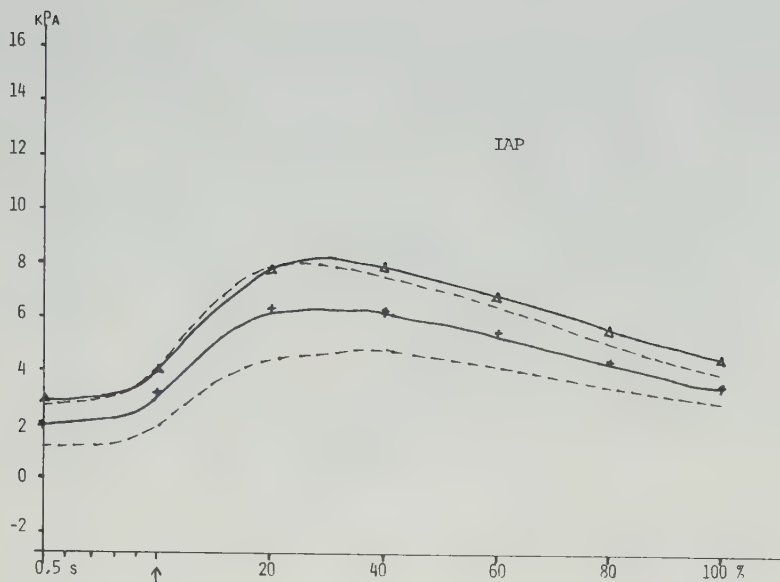


Fig. 2 c.

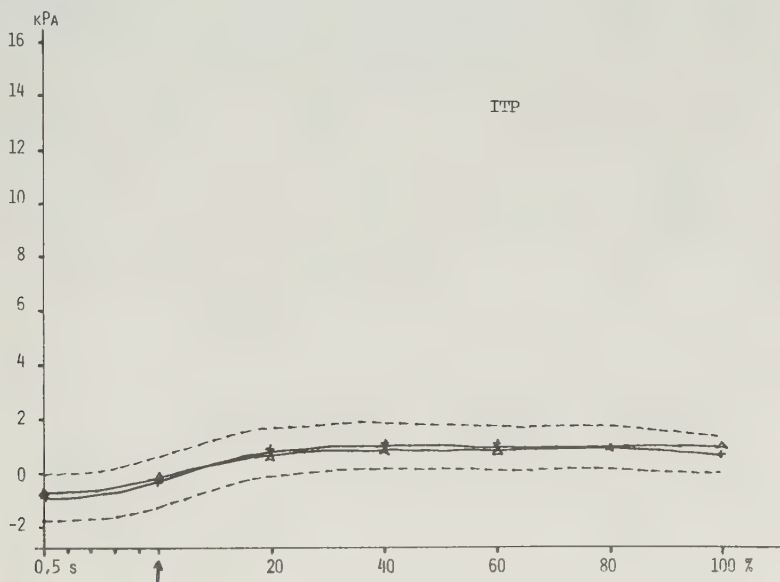


Fig. 2 d.

↑ denotes start of lifting.

+ — + average activity or pressure when lifting without support.

== == == 95% confidence limits of the mean difference between values without and with support.

Δ — Δ average activity or pressure when lifting with support.

For further explanation see text.

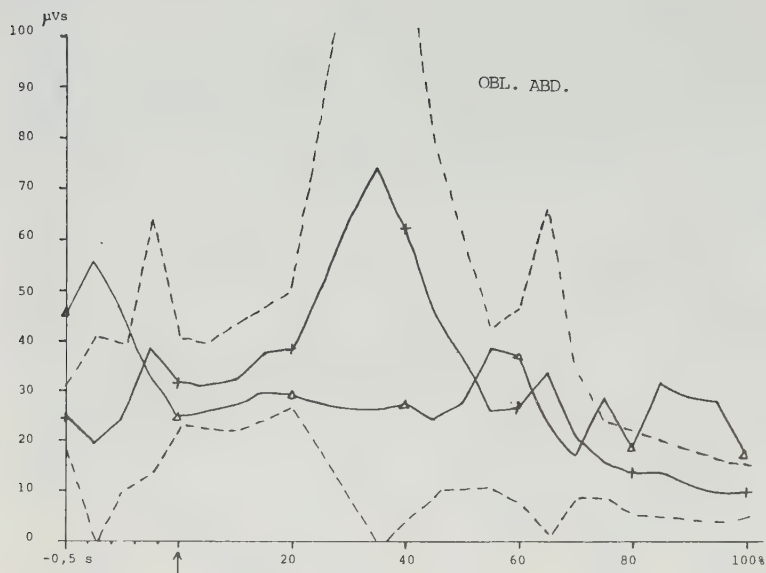


Fig. 3 a.

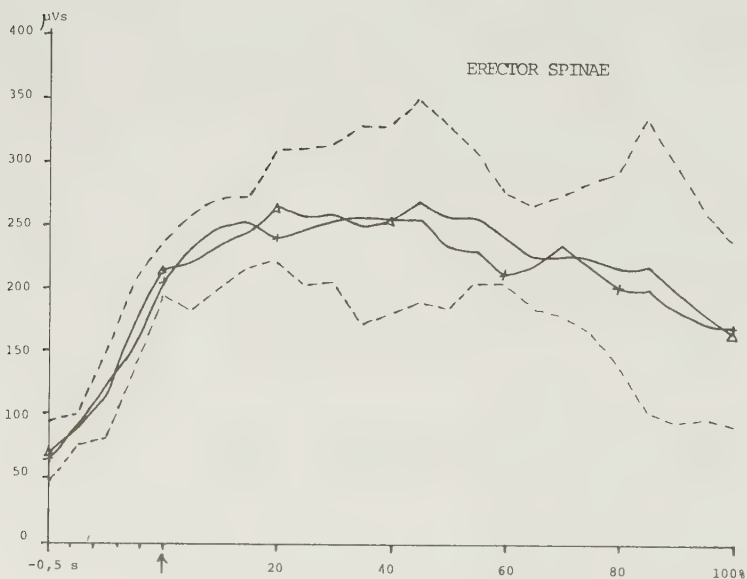


Fig. 3 b. Leg lifting 55 kg by weightlifters with and without a weightlifter's belt.

- a) The oblique abdominal muscles.
- b) The erector spinae muscle.
- c) The intraabdominal pressure.
- d) The intrathoracic pressure.

For explanations see fig. 2.

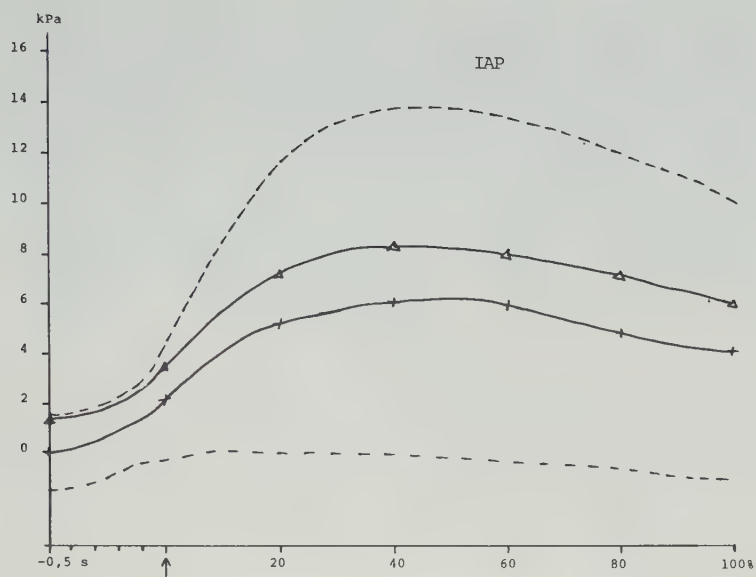


Fig. 3 c.

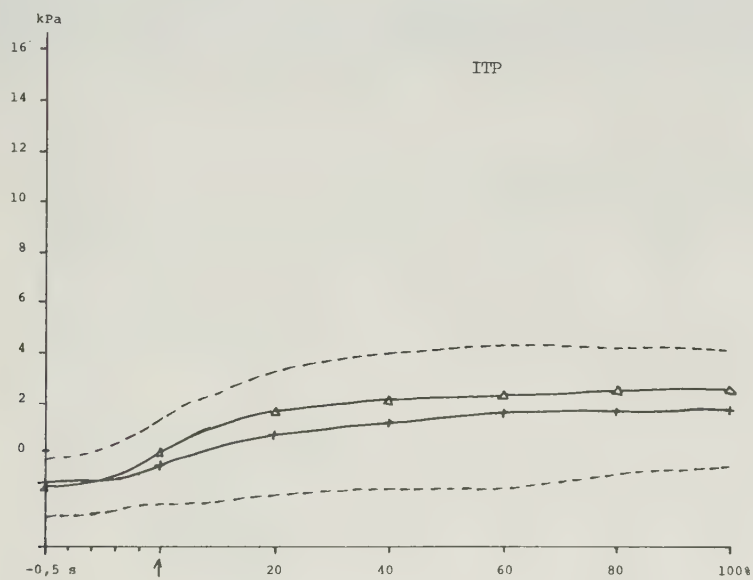


Fig. 3 d.

during the whole lifting time. The increase comprise also the registered periods of 0.5 s. before the lift-off and 0.5 s. after the touch-down and, furthermore. when the subjects performed a lifting motion without any load in their hands. The difference between lifts with and without a support is significant ($p < 0.05$) in the lighter lifts where the absolute values of IAP are lower, but not in the heavier lifts.

4. The intrathoracic pressure did not rise significantly in any instance, but there was a tendency to increased pressures in the back lifts with 10 and 25 kg by 0.5 - 1.0 kPa on average. In the lifts with 55 kg, the highest average increase was 1.3 kPa with the weightlifter's belt and 0.6 kPa with the support of syrlon.

During the 0.5 seconds proceeding the lift-off or following the touch-down, there were generally slight increases by 0.3 - 0.7 kPa on average.

5. Lifting time and patterns of movement

Lifts with a support tended to run somewhat faster than those without a support. The mean differences were, however, small, 0.1 - 0.2 s. out of average times of lifting of 1.6 - 2.0 s. and of lowering of 1.7 - 2.2 s. The tendency was uniform, irrespective of technique and weight of the burden.

Concerning the kinematics of the lifts we could find, by the electrogoniometer, that the subjects during leg lifting performed the knee flexion in exactly the same manner with and without a support, as can be seen in fig. 4, which shows the knee angle during leg lifting with 25 kg. During back lifting there was neither any difference as for the knee angle.

The patterns of activation of the oblique abdominal muscles and of the erector spinae muscle, as reflected by the shape of the average activity curves during the whole lifting and

lowering, were generally, quite unaffected by the use of a support.

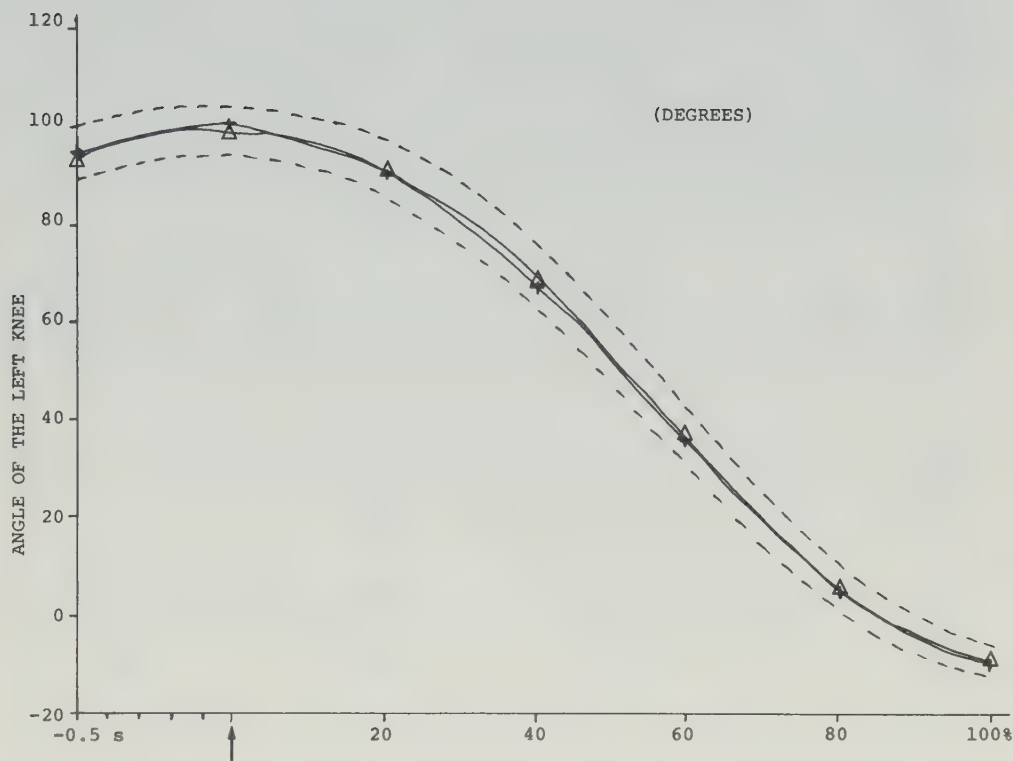


Fig. 4. Knee flexion during leg lifting 25 kg with and without a support of syrlon.

↑ denotes start of lifting.

+ — — — + average angle of the left knee without support with 95% confidence limits of the mean difference between values with and without the support.

△ — — — △ average angle of the left knee with support.

For further explanation see text.

DISCUSSION

Different kinds of braces and corsets have long been prescribed as a part of treatment of low back pain. As prevention, however, such large supports seem unsuitable, for several reasons. Some investigations indicate that they might reduce the abdominal muscle activity in certain situations (10, 14), with detrimental effects in the long run. Moreover, a lumbosacral corset or a similar device is cumbersome in much manual work and thus, in practice, offers no solution.

Nevertheless, some kind of lumbar support seems needed for those individuals who cannot get a sufficient muscular stabilization by themselves and for those with very heavy work. This idea is strengthened by a study by Hoppe (6). She found a reduction of sick-listing among a group of dustmen who wore weightlifter's belts during 15 months of work compared to a similar group of dustmen without a belt.

There are surprisingly few investigations on the physiological effects of lumbar supports in view of the great prescription, and none, to our knowledge, on the effect of a belt. The plan of this study was extended to include also a somewhat broader support of non-elastic material, which might compress the abdomen more than a belt and yet feel comfortable.

The effect on trunk muscle activity

It was considered most important to investigate the effect of the two supports on the myoelectrical activity of the oblique abdominal muscles and of the erector spinae muscle. In this respect our results were very definite throughout the study, as we for all types of lifts found the same average activity with and without a support, whether the lifting motion was done without a weight or with 55 kg, whether by a low back patient or by a weightlifter. As for the myoelectrical activities there was no difference between the two supports tested.

The pressure from the supports on the surface electrodes might reduce the distance between skin and active muscle and thus in-

crease the amplitude of the myoelectrical activity. The overall almost identical average curves with and without a support seem, however, to indicate that there was no important change of recording due to the supports.

There is no previous study on the effect of support during lifting. Morris et al (10) studied the effect of a non-elastic lumbosacral corset containing a rubber bladder covering the abdominal wall and inflated "to the limit of comfort" during static loading, i.e. pulling a strain ring with the trunk vertical and in three different flexed postures. With wire electrodes in the rectus abdominis and in the oblique abdominal muscles from the right upper quadrant of the abdomen they found a marked reduction of activity during all these pulls.

Waters & Morris (14) studied the effect of a chairback brace and of a lumbosacral corset during standing at rest and during walking on a level treadmill and a 5-degree inclined treadmill at different speeds. With wire electrodes in the rectus abdominis and the external and internal abdominal muscles they found an unchanged or decreased activity in the different instances.

The apparent disagreement between those previous results and ours may be related to the facts that our smaller supports, though non-elastic, might interfere less with the oblique abdominal muscles than the larger braces and corsets, and that the pattern of activation at lifting is quite different from those of the other activities studied.

We did no recordings from the rectus abdominis, as this muscle also without a support is only slightly activated during lifting (1, 10).

Concerning the back muscles, we used surface electrodes located at the L2-L3 level and over the most prominent part of the muscles when contracted by hyperextension in the prone position. According to Jonsson (8) these electrodes should pick up the myoelectrical activity from the erector spinae, or more pre-

cisely the iliocostalis lumborum, the longissimus thoracis and, more or less, the multifidi. These muscles are known to be activated simultaneously during flexion-extension (9, 13), during standing with a load in front of the body (8) or during standing in a flexed posture (7). Our results during lifting are in accordance with those of Morris et al (10) during static loading (pull in flexed postures). They both seem to demonstrate that the erector spinae muscle is generally not affected by any support when compensating for ventrally applied loads. In other situations, a brace or corset may decrease or increase the activity of the erector spinae, as during standing at rest or fast walking respectively (14), which may have clinical implications.

The effect on the intraabdominal pressure

There were moderate but consistent increases of the intraabdominal pressure during all lifts, amounting to 1-3 kPa, and unrelated to the weight of the burden. These increases were also seen before lift-off and after touch-down and even when the subjects performed a lifting motion with no load at all.

Three low back patients reported pain during some of the lifts without a support. Two of them also felt pain during the corresponding lifts with a support. None of the weightlifters reported any pain during the tests. Any interference on the results from pain can, thus, be disregarded.

Our findings in postures without an external load agree with Morris et al (10) and Grew & Deane (2) who also found an increase of about the same order at rest, lying, sitting, walking, ascending stairs and similar activities.

When lifting 15 kg, Grew & Deane found a tendency towards increased pressure (about 1 kPa on average) in the low back patients but not in the healthy subjects, which agrees with our findings in the patients.

It seems to us most probable that the effect of our two sup-

ports was purely mechanical, i.e. compression of the abdomen, without interfering with the patterns of activation of the trunk muscles during lifting. There was no difference between the support of syrlon and the weightlifter's belt in this respect.

During isometric pull in flexed postures corsets and braces seem to work differently, as the abdominal muscle activity decreased and the intraabdominal pressure did not increase (10).

The effect on the intrathoracic pressure

The intrathoracic pressure during rest is related to the respiration, the closure of the glottis, the width of the thorax and the position of the diaphragm. How much the intraabdominal pressure is transmitted to the thorax during lifting mainly depends on the ability of the diaphragm to withstand the pressure from below and moreover the intrathoracic pressure level varies whether the glottis is closed or not (5).

It seems clear from this study that the increased intraabdominal pressure during postures without an external load was only partly transmitted to the thorax.

During back lifts and the heaviest leg lifts (with 55 kg) there were slight increases of the intrathoracic pressure, 0.5-1.3 kPa.

Morris et al (10) reported inconsistent differences during isometric pull with and without an inflatable corset. In both instances the pressures are fairly high (about +7 kPa), indicating firstly that the subjects closed the glottis during the pulls and secondly that this static pull is quite different from the dynamic lifting.

The biomechanical effects of lumbar supports of any kind are complicated and beyond the scope of this study. It should only be pointed out that they may act by stabilizing the trunk, by unloading the lumbar spine (12), by reducing the ranges of mo-

vements (2), by warming the dorsal skin (2), and by reminding the subject of the care of his back.

Summary and conclusion

This study has shown that it is possible to use a lumbar support of non-elastic material or a weightlifter's belt during lifting up to 55 kg without interfering with the activation of the oblique abdominal muscles and the erector spinae muscle. Either support made the intraabdominal pressure rise moderately before, during and after all types of lifts, while the intrathoracic pressure was only slightly increased during some types of lifts.

These results apply only to the two tested types, intended primarily for intermittent use as prevention. It should be pointed out that this study deals with the immediate effect of the two supports and not with the possible effects of constant use for a long time. Ordinary work for most people implies a training which they might be deprived of if wearing a lumbar support constantly. There are some indications from previous studies (e.g. 2, 10, 11, 14) that the wearing of corsets and braces might reduce the activity of abdominal or back muscles in certain instances. The risk seems to be minor in the case of the smaller supports and belts used here, but this yet needs further study.

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The Causal Factors of the Intraabdominal Pressure Rise during Lifting, including the Effects of Respiration.

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INTRODUCTION

The intraabdominal pressure (IAP) has been regarded as important for the function of the lumbar spine. It is supposed to stabilize the trunk and unload the lumbar spine at heavy tasks, such as lifting (2, 4, 6, 7, 9, 10, 15, 16, 25, 26, 31, 36). As for the building up of the IAP, interest has been focused on the anterior abdominal muscles which are thought to initiate the pressure rise, except for the rectus abdominis which remains inactive during lifting of small or moderate weights. Recent investigations (18, 20, 29), showed, however, that strengthening of the abdominal muscles did not generally affect the IAP during lifting. Moreover, the oblique abdominal muscles seemed to be of minor importance for the IAP in those situations (18, 20). It thus seemed desirable to clarify the factors responsible for the IAP during lifting, in order to find out possible ways by which the mechanism can be influenced so as to prevent low back pain.

The abdominal cavity, containing mainly liquid and semisolid material, is surrounded by muscles, anteriorly by the rectus abdominis, laterally by the external and internal oblique abdominal muscles and the transversus abdominis, above by the diaphragm and below by the muscles of the pelvic floor. The dome-shaped diaphragm divides the abdomen from the air-containing thorax. The transdiaphragmatic pressure difference (Pdi) reflects the tension and the position of the diaphragm and may be used to estimate the part played by the diaphragm in the building up and maintenance of the IAP.

When lifting heavy burdens most people, also weightlifters, inspire and hold their breaths. There are, however, no systematic studies about the effects of different breathing techniques on the intrathoracic (ITP) and intraabdominal (IAP) pressures and hence on the stability of the trunk during lifting.

The aim of this study was to analyse first the effects of respiration on the IAP during lifting and secondly the activation

Table I. Characteristics of the subjects.

	Healthy subjects	Low back patients	Weight-lifters
Number	20	20	10
Age (years) mean range	28 23 - 33	32 22 - 37	23 18 - 28
Height (m) mean range	1,80 1,71-1,87	1,80 1,74-1,88	1,74 1,61-1,88
Weight (kg) mean range	75 65 - 85	76 57 - 89	80 58 - 123
Trunk flexion strength (N) mean SD	721 136	549 114	850 269
Trunk extension strength (N) mean range	859 130	821 166	1091 277
Duration of low back pain (years) median range	- -	5,5 2 - 18	*
Duration of weight lifting (years) median range	- -	- -	6,5 2 - 12

* see text

pattern of the muscles possibly involved in the initiation and maintaining of the increased IAP during lifting.

MATERIAL

Fifty male volunteers took part in different sections of this study. Twenty of these were subjects with no history of low back pain, as previously described (18). The next twenty, also selected from the construction industry, were suffering from more or less continuous low back pain for 2-18 years (median 5,5 years) without sciatica or any other complicating diseases. They have also previously been mentioned (19). The last ten subjects were very skilled weightlifters, who had been training for 2-12 years (median value 6,5 years). Three of them were national champions in their respective weight classes. Three of the weightlifters reported previous minor low back complaints of short duration and two had had intermittent low back pain for 1-3 years but not during the year before the examination.

Table I gives the ages, heights and weights of all the subjects and also the strength of the trunk flexors and of the trunk extensors recorded by strain-gauge in the upright position as previously described (19). In the low back patients we found local tenderness and suspected instability in the lumbosacral and/or the adjacent lumbar segments. Apart from these findings, routine examination of the back, hips and other joints, and other routine tests were quite normal in all cases. There were no signs of pulmonary, cardiac or abdominal disorders. None had a suspected inguinal hernia.

One of the healthy subjects, eight of the low back patients and all the weightlifters had previously had some instruction in lifting technique. Before the examination the healthy subjects and the patients were instructed as regards leg lifting.

One of the low back patients had been using a corset in leisure time for six years and another a weightlifter's belt for six months. All the weightlifters generally used leather belts for the heaviest training and at competitions.

METHODS

Electromyographic recordings

The myoelectrical activity was recorded by surface electrodes for the oblique abdominal muscles and the erector spinae muscle and inserted wire electrodes for the puborectalis muscle.

On the healthy subjects we used disposable surface electrodes (45037 4EH019 Siemens Elema) with an interelectrode distance of 3 cm as previously described (18). The pairs of electrodes were placed over the left oblique abdominal muscles at umbilical level and above the ventral iliac spine and over the left erector spinae muscle at the level of the spinosus processes L2-3. The direction of the electrodes was parallel to the direction of the muscle fibers. The signals were fullwave rectified and integrated with Siemens Integrator EMT 43 B over a preset period of 0,3 s. and registered on a mingograph (Mingograf 82 Siemens Elema) together with the raw EMG for visual control.

On the low back patients and the weightlifters we used another disposable surface electrode (3M Red Dot 2247 Ag/AgCl) with an interelectrode distance of 5 cm over the same muscles with the same direction, but on the right side, as previously described (18).

Three healthy subjects were reexamined together with the patients and the weightlifters and then supplied with the Red Dot electrodes for the oblique abdominal muscles and the erector spinae. Besides, they were supplied with insulated bipolar fine-wire electrodes (Nikrotal LX, 0,05 mm in diameter) from which about 3 mm of the insulation was burnt off in a flame. They were prepared according to Basmajian (3), with the modification that the two electrodes were inserted with two separate carrier needles. Guided by an index finger in the ampulla recti the two needles, dorsolaterally from the anus, were put through the ischiorectal fossa to, but not into, the puborectalis muscle, the most prominent part of the levator ani muscle. After withdrawal of the needles, the two hooked and bared wire ends were located close to the lower margin of the muscle, about 1 cm apart. By spring-wire coil connectors (3) and screened cables, the electrodes were connected to preamplifiers fastened to the subject's waist.

As for the patients, the weightlifters and the three reexamined healthy subjects the myoelectrical signals after preamplification were further amplified and recorded on magnetic tape. During recording the signal quality was continuously checked on the mingograph. For analysis, the myoelectrical signals were full-wave rectified and integrated over a preset period of 0,1 s.

Intraabdominal and intrathoracic pressure recordings

The intraabdominal (i.e. intragastric) pressure was recorded in all cases, and the intrathoracic (i.e. intraoesophageal) pressure in the patients, the weightlifters and the three healthy subjects, mentioned above.

The pressures were recorded via open polyethylene catheters filled with saline and without balloons, as previously described (21). The three thin polyethylene catheters (Portex 100 with an internal diameter of 0,86 mm), fused distally, were introduced through the nose to the upper part of the stomach. The pressure changes during respiration told us when the opening at the lower end rested in the stomach, and the second opening 25 cm proximally rested in the oesophagus. The third catheter contained air and was intended only as a guide. The pressure curves were recorded simultaneously with the myoelectrical signals on the mingograph and the tape, and the catheters were flushed with saline when necessary.

The pressure recording system was tested according to Asmussen, Lindström, and Ulmsten (1). The rise time was found to be 0,015 s., the settling time 0,1 s. and the overshoot 26% in repeated recordings, which was considered adequate for analysis of the frequencies occurring.

From X-ray films during pressure recording we calculated the source of error due to the external location of the transducer and corrected the pressure values accordingly.

Respiration recording (fig. 1)

A new flow-meter was constructed for recording the respiratory flow without

motion artefacts (Bengt Månsson, BM Elektronik, Åhus, Sweden). It is based on the vortex principle and consists of a tube, a mouthpiece, an ultrasound unit and a termistor. Inside the tube, on either side of the unit, is a triangular shaped pole that converts the straight air flow into a turbulent one. The turbulence is detected by ultrasound across the tube, and the result will be a pulse frequency proportional to the air flow. The termistor tells whether the air is passing in or out, and the signals from the ultrasound unit give the volume passed per time unit by integration.



Fig. 1. The respiration recording system. The ultrasound unit is located on the middle of the tube and the termistor in the distal opening. Note the spring-holder on the nose and the catheters for the pressure recordings.

The lifts

Lifts were done with "leg lifting" as well as "back lifting". By "leg lifting" is meant symmetric lifts with bent knees and the back as straight as possible. "Back lifting" was used for lifting with straight knees and bent back.

Each subject could choose his own lifting pace. Otherwise the lifts were carefully standardized to facilitate comparisons. The subject stood in a

fixed position relative to the load and a physiotherapist gave instructions about the technique to be used. Each lift was done twice and the subjects were allowed to rest between the lifts.

The lifts were performed from floor level to the upright position with the load on extended hanging arms in front of the body.

In all lifts, a specially made box was used, 40x25x16 cm, with symmetrical handles 11cm from the floor. The box could be loaded symmetrically with 5 kg weights, and was supplied with an accelerometer for recoding vertical acceleration and deceleration. For the patients and the weightlifters a switch was also attached to the box for recording of lift-off and touch-down. Another switch was then placed behind the subjects at the Th3-4 level when standing erect, recording the end of the lifting and the start of the lowering. In the lifts by healthy subject we determined these points by the accelerometer.

Finally, the lifting movements were recorded by an electrogoniometer on the left knee and by super-8-film or videotape.

The examination procedure

Table II lists the different lifts included in this study.

Table II. Types of breathing techniques studied and different modes of analysing the IAP during lifting. The figures to the left refer to the text.

		Healthy subjects		Low back patients		Weightlifters	
		No Subjects	No Lifts	No Subjects	No Lifts	No Subjects	No Lifts
1	Lifts after max. inspiration	20	80				
2	Lifts after max. expiration	20	80				
3	Lifts during expiration without facilitation			20	160	10	40
4	Lifts after expiration with facilitation	20	160				
5	Lifts with natural respiration technique	20	160	20	160	10	40
6	Lifts with recording of respiration			20	80	10	80
7	Lifts with recoring of respiration and EMG from the puborectalis muscle	3	54				
8	Lifts with great IAP variations within or between subjects			3	36	5	69
9	Peak IAP during lifting in relation to P_{di_max} during the Mueller manoeuvre.			20	120	10	60

One part of this investigation dealt with the effect of different breathing techniques. Here these lifts are compared to the corresponding lifts performed without any instruction about the respiration.

1. After a maximal inspiration the healthy subjects held their breaths and lifted 25 kg with leg lifting and back lifting.
2. After a maximal expiration the healthy subjects held their breaths and lifted 25 kg with leg lifting and back lifting.
3. During expiration the patients lifted 10 kg and 25 kg and the weightlifters 40 kg, all loads with leg lifting as well as back lifting.
4. The healthy subjects lifted 25 kg and 40 kg with back lifting as well as leg lifting using a special technique suggested by Lewit (30) to facilitate the abdominal muscles. The subjects start with a maximal inspiration. They then raise on the forefeet, and go down to the soles again at the same time as they, during expiration, bend to take the box. The lift itself was then performed with their natural breathing technique.
5. All the lifts above were done by the same subjects with the same lifting technique except for the breathing instructions or facilitation movements.

The second part of this investigation was intended to analyse the different causal factors of the IAP rise during lifting.

6. The patients lifted 25 kg and the weightlifters 40 kg with leg lifting as well as back lifting while we recorded their natural breathing techniques.
7. Three healthy subjects, who were found to be "highpressurizers" or "lowpressurizers" in a previous study, were asked to lift 25 and 40 kg with leg lifting and back lifting and while actively trying to contract the pelvic floor muscles.
8. In a simultaneous study of the effect of abdominal muscle training, pre-

viously described (20), we found three low back patients who showed great differences of IAP after training, in contrast to the average effect. They offered a possibility to study variations in patterns of muscular activation and their leg lifts of 25 and 40 kg and their back lifts of 40 kg were included in this study.

The same holds true for five of the weightlifters who showed interesting variations in leg lifts with 40 and 55 kg and back lifts with 40 kg.

9. The patients and the weightlifters performed the Mueller manoeuvre (12, 34), before and after the abdominal muscle training mentioned above. At each occasion three consecutive tests were performed. After an ordinary expiration, when the subject was supposed to be roughly at the position of functional residual capacity (FRC), he was asked to perform a maximum diaphragmatic inspiratory effort with the mouth and nose closed. Before this, the subjects had, during attempted inspiration, practised pushing the abdominal wall outwards and avoiding rib cage expansion. The maximum transdiaphragmatic pressure ($P_{di_{max}}$) during the Mueller manoeuvre was then compared to the peak IAP during lifting.

Fig. 2 summarizes the methodology used in this study. With the healthy subjects in moments 1, 2, 4, and 5 the computer was omitted. Table II shows when the respiration system and the EMG of the puborectalis muscle were used.

Evaluation procedure, including statistical methods

Throughout the study all lifts were performed twice and the calculations were made from the mean values of these two lifts.

For the healthy subjects registrations were made during moments 1, 2, 4, and 5 of all signals from the EMG of the oblique abdominal, the erector spinae, and the lateral vastus muscles, from the IAP and from the accelerometer and the signals were recorded in the mingograph. From these curves we then calculated manually the peak IAP and the values of the integrated EMG during 0,3 s. coincidentally with the peak.

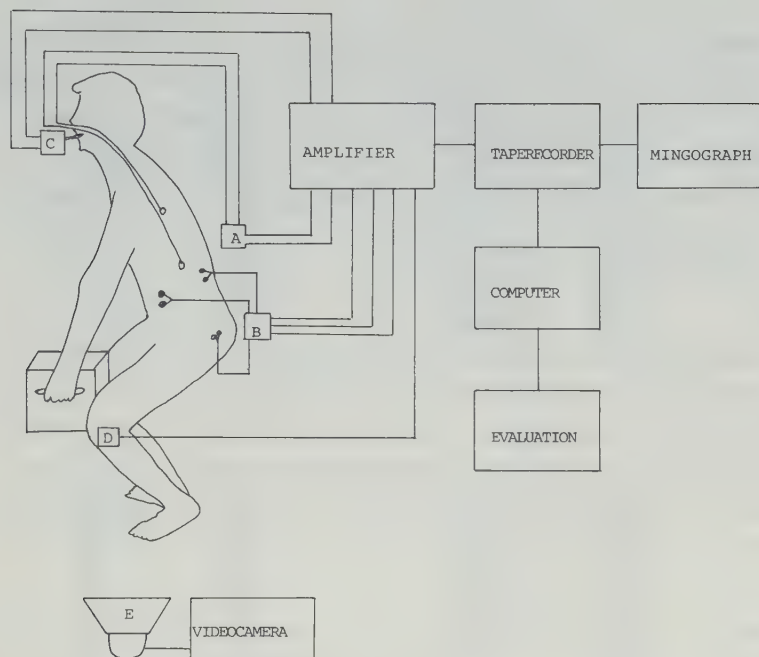


Fig. 2. Schematic view of the methods used in this study. For details see text. A. Pressure recording system. B. EMG recording system. C. Respiration recording unit. D. Electrogoniometer. E. Video camera.

For the rest of the lifts the analogue signals from the EMG of the oblique abdominal and the erector spinae muscles, from the IAP and ITP, from the electrogoniometer and from the accelerometer were simultaneously recorded on magnetic tape. The same applied to the EMG of the puborectalis muscle and the respiration recording, whenever applicable. All information was then put into a computer where the myoelectrical signals were full-wave rectified and integrated over preset periods of 0,1 s. each containing 400 readings. The other signals were all averaged over the same periods of 0,1 s. and converted digitally. The registrations comprise the periods from 0,5 s. before the lift-off to the end of the lifting and from the start of the lowering to 0,5 s. after the touch-down.

During the Mueller manoeuvre we recorded the maximum transdiaphragmatic pressure ($Pdi_{\max} = [IAP - ITP]_{\max}$).

Concerning the moments 1, 2, 4, and 5 the design of the study was chosen to get a matching situation where each subject could be compared to himself while performing a certain lift with and without modification. Here the analysis of significance was performed with the IAP and EMG values according to Student's t-test, and the strength of covariance was determined by Pearson's correlation coefficient, r . This applies also to moments 6 and 9 as regards the calculations.

Concerning the moments 3 and 5 the analysis of significance was extended and carried out throughout the whole lifting procedure by calculating the 95% confidence limits of the mean difference between values with and without modification of the lifts. As the time varied between lifts, the time was then normalized and expressed as percentages of the whole time, and for lifting and lowering separately, it runs from 0 to 100%.

Concerning the moments 7 and 8 each separate lift was plotted to determine the mutual relationship between the parameters in case. The time was also here normalized, as described above. Each integration period of 0,1 s. then covers 5-6% on the abscissa.

RESULTS

1. The effects of breath holding after maximal inspiration

Maximal inspiration before followed by breath-holding during lifting did not affect any of the three parameters, neither the peak IAP nor the myoelectrical activities of the oblique abdominal muscles and the erector spinae muscle during 0,3 s. coincidentally with the peak (fig. 3).

The average lifting times varied very little, 0,06 s. out of the average lifting times of 1,78 - 1,94 s. The same applied to the times when the IAP and the myoelectrical activities of the oblique abdominal, the erector spinae and the lateral vastus muscles reached their highest values during the lifts.

2. The effects of breath holding after maximal expiration.

Fig. 3 shows that this type of breath holding did not either

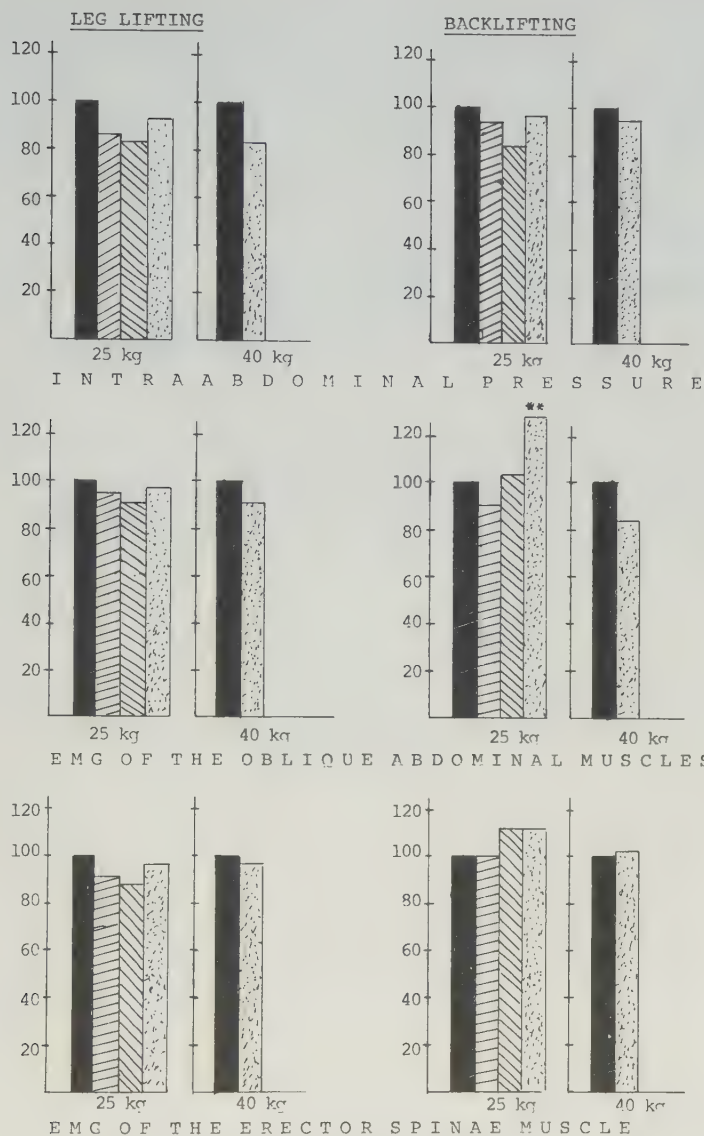


Fig. 3. Effect of different breathing techniques on the peak IAP (upper graphs), the EMG of the oblique abdominal muscles (middle graphs), the EMG of the erector spinae muscle (lower graphs). The myoelectrical activities refer to the period of 0,3 s. around the peak IAP. The average values are expressed in percentages of the corresponding average values when the subjects lift with their own natural breathing technique.

- lifting with natural breathing technique.
- ▨ lifting during breath holding after maximum inspiration.
- ▩ lifting during breath holding after maximum expiration.
- ▤ lifting after expiration with facilitation.

xx denotes $p < 0,01$. All other differences: N.S.

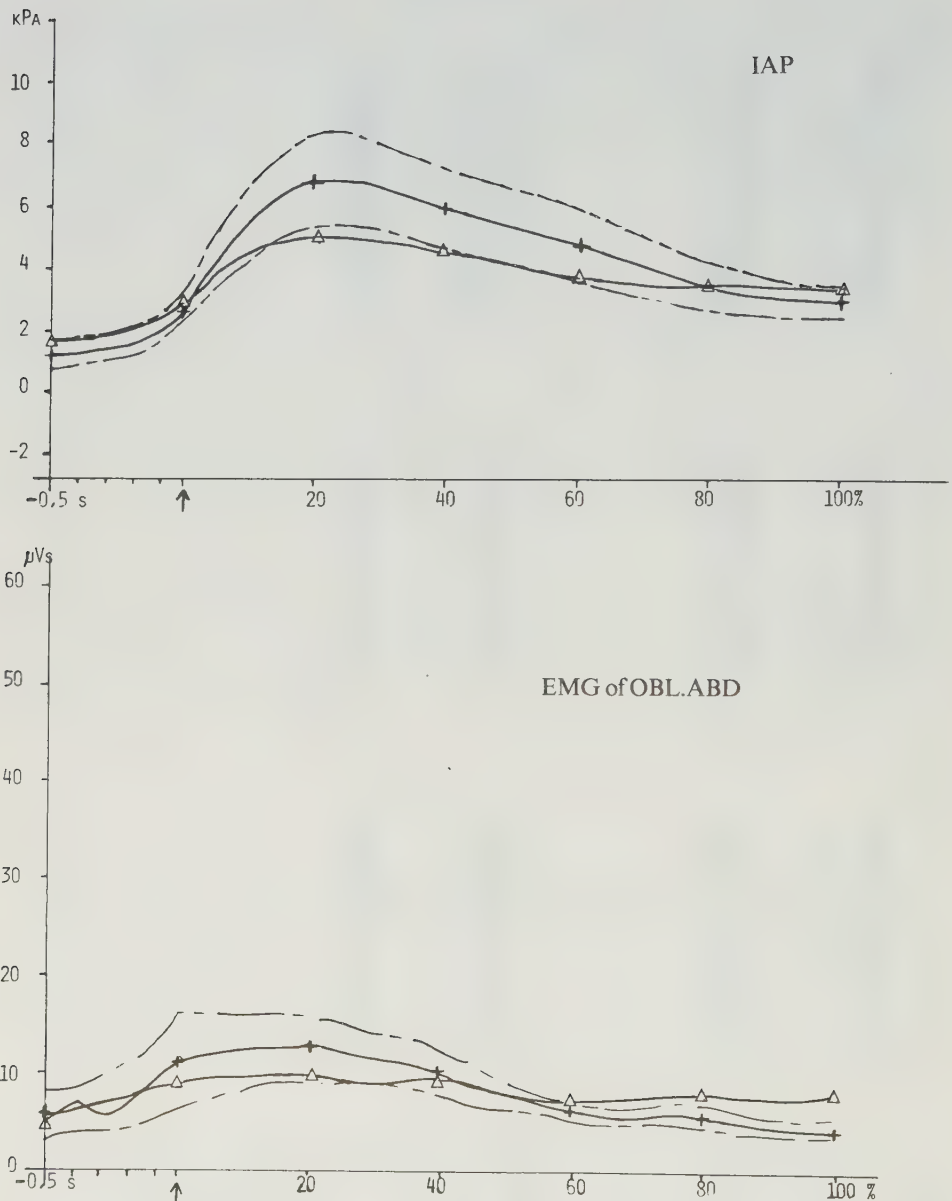


Fig. 4. Leg lifting 25 kg by low back patients in two ways of breathing.

↑ denotes start of lifting.

+ ——— + average pressure or activity when lifting with natural breathing.

— — — 95% confidence limits of the mean difference between values for the two breathing techniques.

Δ ——— Δ average pressure or activity when lifting during expiration. The difference is significant ($p < 0,05$) when this line is located outside the confidence limits.

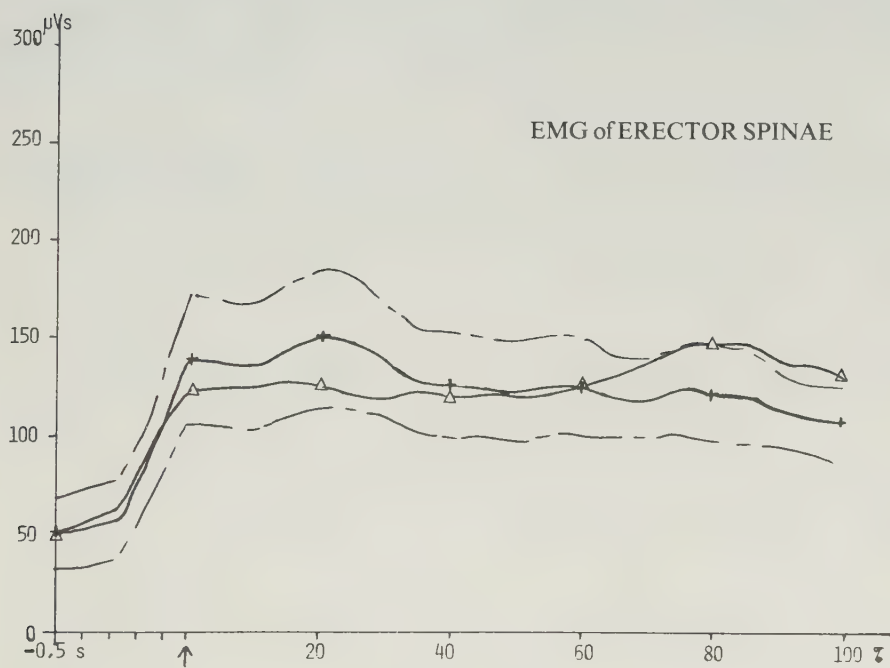
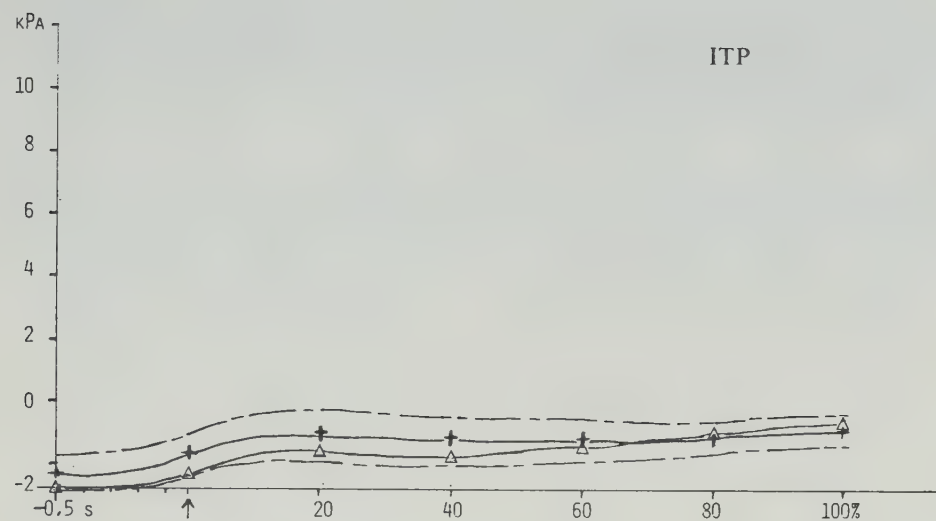


Fig. 4.

affect any of the three parameters significantly. Neither the total lifting times nor the times of peak values were influenced materially.

3. The effects of expiring during lifting.

Fig. 4 illustrates the effects in one instance (leg lifting 25 kg). The intraabdominal pressure decreased significantly during 30% of the lifting time with leg lifting 25 kg. In all other instances with 10, 25, and 40 kg, lifting as well as lowering, there were no significant changes compared to lifting with natural breathing.

The intrathoracic pressure decreased significantly during the liftings and lowerings with 40 kg, leg lifting as well as back lifting. The average differences were 3-4 kPa. For the lifts of 10, and 25 kg there were no significant changes but a tendency towards lower values in some instances.

The myoelectrical activity of the oblique abdominal muscles increased significantly during the last phase of lifting with 25 kg (leg lifts and back lifts) but otherwise there were no changes in any instances.

The myoelectrical activity of the erector spinae muscle was quite unaffected in all instances, lifting or lowering, leg lifting or back lifting, irrespective of the weight of the burden.

The patterns of activation as reflected by the average curves were quite unaffected by the expiration (see fig. 4).

4. The effects of facilitation

The next question to arise is whether the proposed facilitation manoeuvre adds anything to the above. These lifts were examined by the same methods as moments 1 and 2.

Fig. 3 shows that the peak IAP was quite unaffected in all

instances. The average activity of the oblique abdominal muscles was significantly increased with back lifting 25 kg but in all other instances the muscular activity around the peak IAP was not significantly affected.

The average lifting time were not significantly changed by the facilitation technique which was easy to learn and use. Nor did the times for the maximum IAP and myoelectrical activity alter markedly.

5. The natural breathing during lifting.

In 160 lifts by the patients and the weightlifters we recorded the subjects' natural breathing. After becoming familiar with the apparatus that forced them to breathe through the mouth but gave no noticeable resistance, they were asked to lift as usually.

Table III shows how the two groups breathed naturally. For 20-45% of the cycles they held their breaths. For the rest they seemed most commonly to expire when lifting and inspire when lowering. Some started by holding their breaths and changed to breathing in or out during the movements, others began to inspire or expire before lifting or lowering. The weightlifters seemed often to take deeper breaths than the patients.

It seemed clear from all curves that breathing during lifting is inconsistent with a positive intrathoracic pressure.

For both patients and weightlifters who breathed there was no definite correlation between the breathing volumes and the intrathoracic pressure.

Nor was there any significant correlation between the breathing volumes and the peak intraabdominal pressures, neither for the patients nor for the weightlifters.

Table III. Natural breathing during lifting and lowering, expressed as volume of air passed through the respiration tube from the lift-off to the end of lifting and from the start of lowering to the touch-down. Number of lifts within parentheses.

Volume of air	Low back patients		Weightlifters	
	25 kg		40 kg	
	Lifting %	Lowering %	Lifting %	Lowering %
0,1 l	45	36	27	20
Inspiration 0,1 - 0,8 l ^{x)}	17	50	0	47
>0,8 l	0	0	2	13
Expiration 0,1 - 0,8 l ^{x)}	38	14	62	20
>0,8 l	0	0	0	0
Total	100 (69)	100 (50)	100 (56)	100 (40)

x) In a few single cases the subjects breathed in and out a little during the lifting or lowering. The table then shows the net volume of air passing the tube.

6. The Mueller manoeuvre

The patients could produce an average maximal transdiaphragmatic pressure of 10,4 kPa (SD = 4,23) and the weightlifters of 8,3 kPa (SD = 4,09). The test showed fairly good reproducibility in repeated trials within the same subject (SD = 1,88 and 2,27 kPa respectively for the patients and the weightlifters).

The Mueller manoeuvre is regarded as a test of the strength of the diaphragm (12,34), and it was therefore interesting to try the correlation between the Pdi_{max} and the peak IAP during different lifts. Table IV shows that for the patients there was a positive correlation, significant in nine out of twelve instances. For the weightlifters we could find no correlation in any of the lifts with 25 and 40 kg.

Table IV. Correlation between the maximum transdiaphragmatic pressure ($P_{di_{max}}$) during Mueller manoeuvre and the maximum intraabdominal pressure (peak IAP) during lifting.

Lifting techniques	Weight (kg)	Patients				Weightlifters			
		Lifting		Lowering		Lifting		Lowering	
		r	p	r	p	r	p	r	p
Leg lifting	10	0,45	<0,05	0,49	<0,05				
	25	0,52	<0,05	0,52	<0,05	-0,28	NS	-0,31	NS
	40	0,31	NS	0,48	<0,05	-0,36	NS	-0,54	NS
Back lifting	10	0,35	NS	0,38	NS				
	25	0,56	<0,01	0,50	<0,05				
	40	0,61	<0,01	0,60	<0,01	-0,07	NS	-0,09	NS

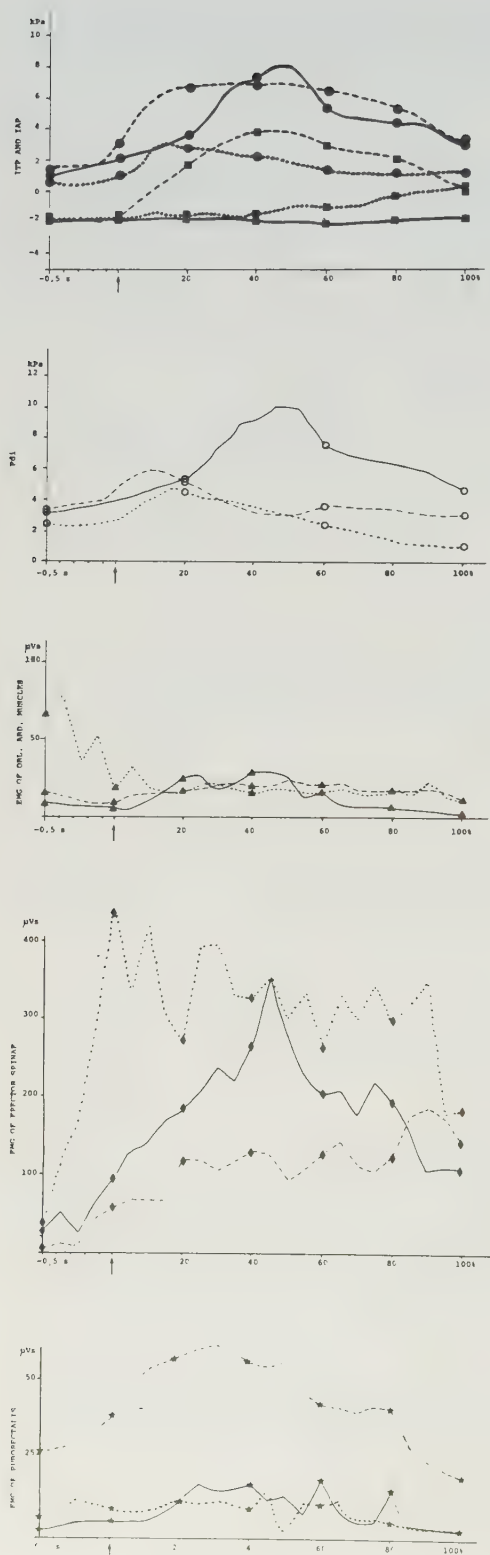
7. The building up of intraabdominal pressure during lifting.

From the lifts noted under moments 7 and 8 in table II we tried to analyse the possible effects on the IAP of the different muscles surrounding the abdominal cavity. This is complicated by the facts that the muscles may well contract so as to increase the pressure but may also contract due to an increased pressure from inside. We then have to consider the timing of the different activities during lifting.

The activity of the diaphragm can be judged by following the transdiaphragmatic pressure difference.

From about 140 graphs illustrating lifts with 25, 40, and 55 kg by the three groups we tried to analyse the interplay between the diaphragm, the oblique abdominal muscles and the puborectalis muscle during lifting, including the relationship between the intraabdominal and the intrathoracic pressures.

Fig. 5 shows three different subjects doing the same lift with different patterns. Fig. 6, 7, and 8 each show a pair



Subject A: —●—
 Subject B: - - -○- - -
 Subject C:●.....
 For further explanation see text.

Fig. 5. Graphs illustrating three healthy subjects performing a leg lift with 25 kg. The top graph gives IAP (●) and ITP (■), then in descending order the transdiaphragmatic pressure difference (Pdi), the EMG of the obl. abd. muscles, the EMG of the erector spinae muscle, and the EMG of the puborectalis muscle. All three lifts start at 0 s and ends at 100 s (of the lifting time). Prior to 0 s denotes time in absolute values.

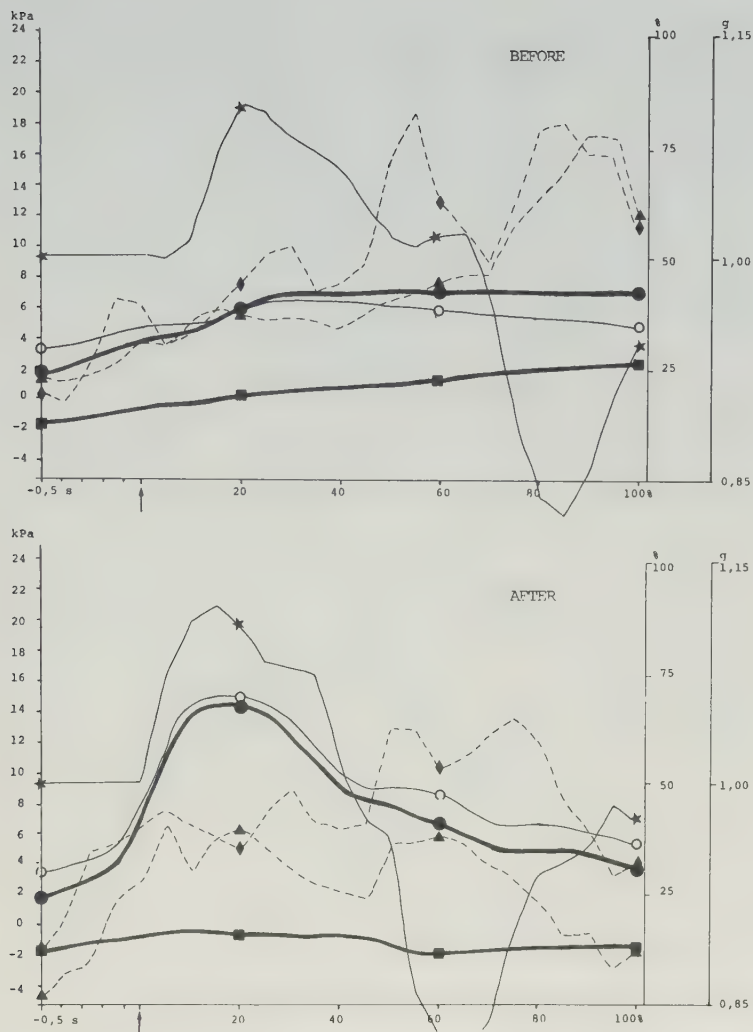


Fig. 6. Patient D lifting 40 kg with leg lift before (a) and after (b) five weeks of isometric abdominal muscle training. ↑ denotes the lift-off. Prior to that point is 0,5 s. in absolute values, while the lifting time is normalized and expressed in percentages of the whole time (from 0 to 100%). IAP, ITP and Pdi are expressed in absolute values (left scale). EMG activity is expressed in percentages (right scale) of the highest value registered at any of the four lifts performed by the same subject with the same technique and with the same weight. The activity level is thus comparable between fig. 6 a and 6 b.

IAP: ● — ●
 ITP: ■ — ■
 Pdi: ○ — ○

EMG obl. abd. m.: ▲ — — — — ▲
 EMG erector spinae m.: ◆ — — — ◆
 Acceleration of the box: ★ — — — ★
 (second right scale)

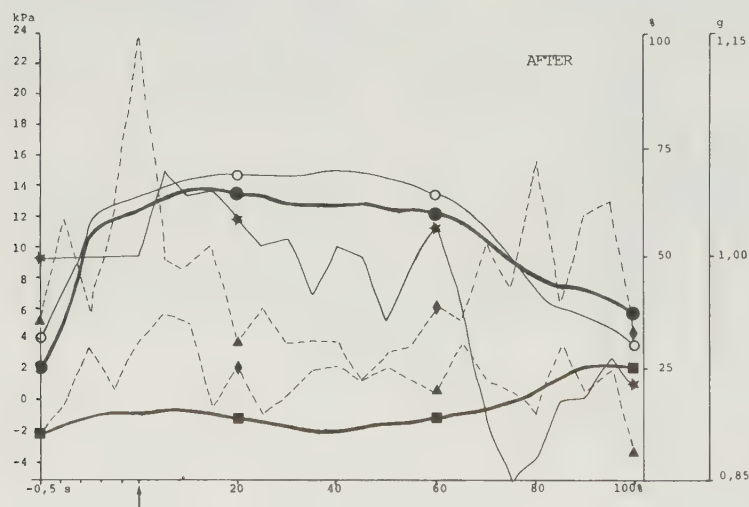
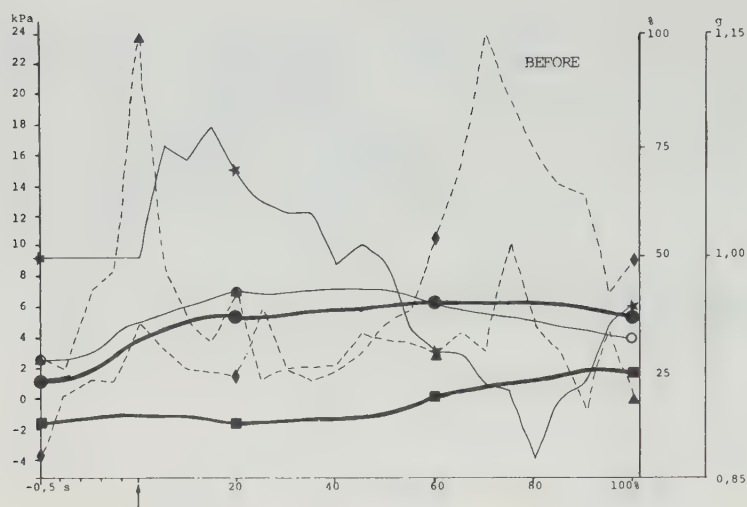


Fig. 7. Patient E lifting 40 kg with back lift before (a) and after (b) five weeks of isometric abdominal muscle training.
For explanation see fig. 6.

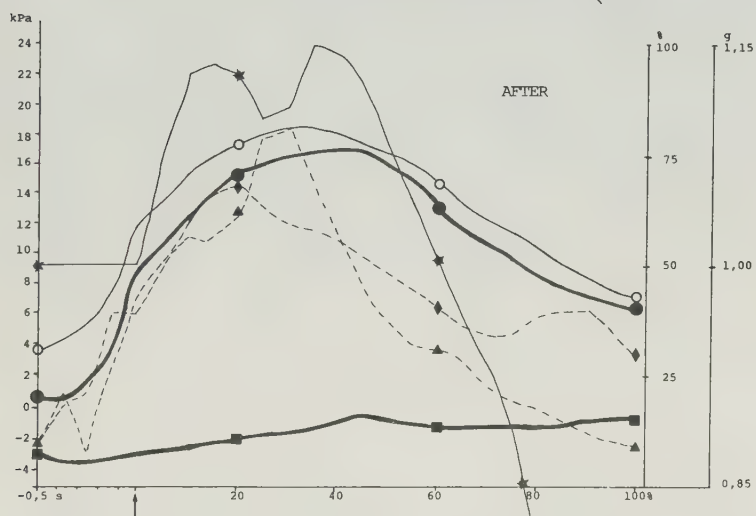
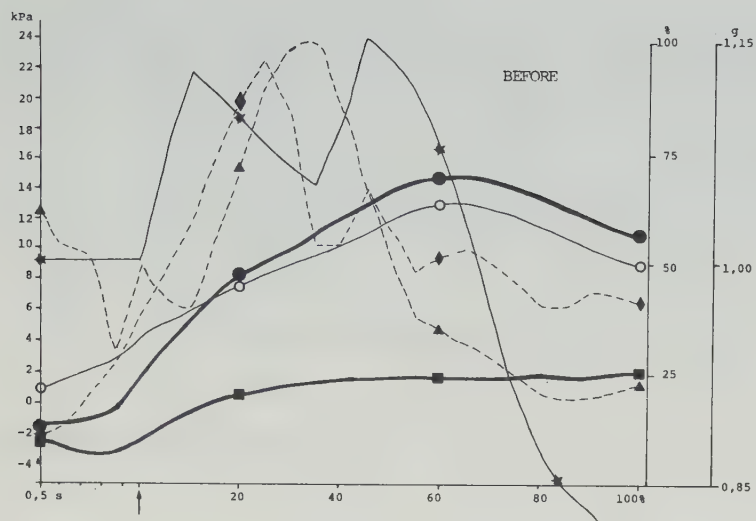


Fig. 8. Weightlifter F lifting 55 kg with leg lift before (a) and after (b) five weeks of isometric abdominal muscle training.
For explanation see fig. 6.

of graphs from one subject lifting the same load before and after abdominal muscle training with the same technique but with different muscular responses and pressures. The results of the analysis may be summarized as follows:

- a) The function of the diaphragm is reflected by the strong correlation between the transdiaphragmatic pressure difference (Pdi) and the peak IAP during lifting (table V). This correlation could also be shown during the whole lifting in many instances, as can be seen from fig. 5 (subject A), 6 b, 7 b and 8 b.

Table V. Relation between peak IAP during lifting and the coincident transdiaphragmatic pressure difference (Pdi).

The weightlifters did not lift 25 kg with backlifting.

Lifting technique	Weight (kg)	Patients				Weightlifters			
		Lifting		Lowering		Lifting		Lowering	
		r	p	r	p	r	p	r	p
Leg lifting	25	0,90	<0,0001	0,82	<0,0001	0,97	<0,001	0,92	<0,05
	40	0,90	<0,0001	0,84	<0,0001	0,91	<0,001	0,95	<0,001
Back lifting	25	0,83	<0,0001	0,85	<0,0001	-	-	-	-
	40	0,91	<0,0001	0,88	<0,0001	0,97	<0,001	0,86	<0,01

- b) *The oblique abdominal muscles.* The myoelectrical activity showed that they were regularly activated during lifting. The activity rose sometimes simultaneously with the pressure rise (fig. 6 b, 8 b), sometimes without any pressure response (fig. 6 a, 7 a).

- c) *The puborectalis muscle.* The myoelectrical activity showed that it was regularly activated during lifting (fig. 5), but the rise of activity varied between the three subjects.

In subject B the rise of activity coincided with the lift-

off, and the pressure rose early in the lifting. In subject A the rise of activity came after 10% of the lifting time, and the pressure rose gradually during the first 50% of the lifting time. In subject C there was a rather weak activity and only a small pressure rise. During lowering the activity was generally lower than during lifting.

When asked to contract the pelvic floor muscle deliberately during the lifting, the three subjects differed in activity. Subject B increased his previously high activity and his peak IAP rose from 7,4 kPa to 18,6 kPa during lifts of 25 kg, despite the fact that the lift was otherwise unchanged and the acceleration of the box was reduced. When subject A was asked to lift while contracting the pelvic floor muscles deliberately, he instead increased the activity of the oblique abdominal muscles and the peak IAP rose from 8,5 kPa to 11,7 kPa. Subject C, on the other hand, activated both the puborectalis and the oblique abdominal muscles but there was no increase of the IAP.

It should also be mentioned that there was no detectable activity at rest, whether standing or sitting (sensitivity 125 - 250 $\mu\text{V}/\text{cm}$). This was also usually true for the instances when the subjects were standing upright with the load in front of the body. On the other hand, the muscle was always activated during trunk muscle strength tests and during the Valsalva and the Mueller manoeuvres.

- d) *The intrathoracic pressure* showed great individual variations (fig. 9). The pressure was negative throughout the lift, successively rising from negative to positive values during the lift or positive throughout the lifting procedure.

The graphs in fig. 5 show, that subject A and C produced about the same negative ITP throughout the lifts, while

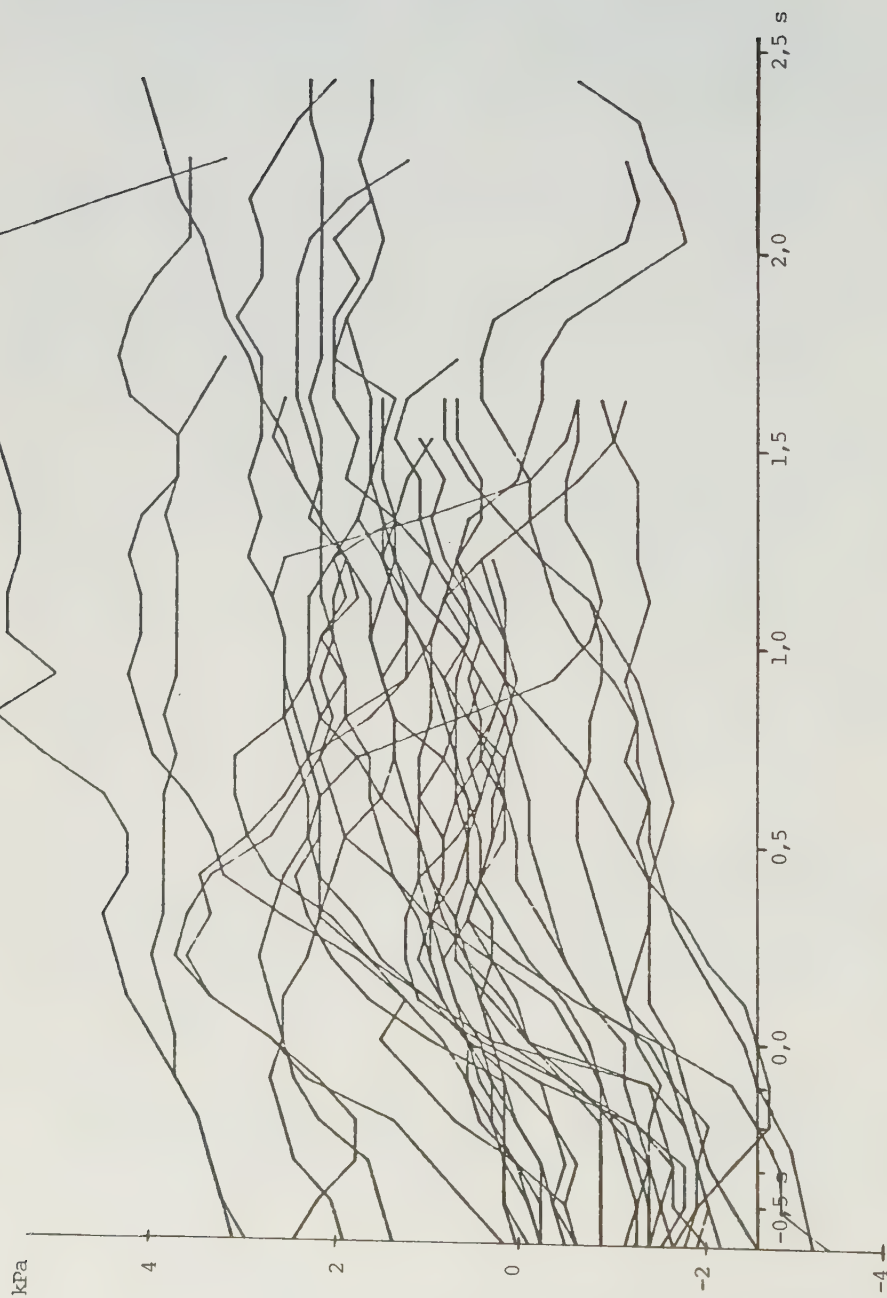


Fig. 9. The intra-thoracic pressure during leg lifting of 25 kg by the low back patients. Each line represents one lift starting 0,5 s. before the lift-off and denoting the real lifting time.

subject B had an elevated and positive ITP, with the shape of the graph similar to that of the simultaneous IAP.

There was no correlation between the peak IAP and the simultaneous ITP among the patients. As for the weightlifters there was a significant correlation in all lifts with 25, and 40 kg ($r = 0,77 - 0,86$, $p < 0,05$) and in lowerings with 40 kg ($r = 0,76 - 0,80$, $p < 0,05$).

DISCUSSION

The first point to be discussed is whether the methods used justify any conclusions about a cause and effect relationship between myoelectrical activity around the abdominal cavity and the pressure within the cavity.

The time interval from the myoelectrical activity to the mechanical response, i.e. the electromechanical delay, was estimated to 0,02 - 0,05 s. for the biceps and triceps brachii muscles (33) and up to 0,05 - 0,10 s. for the abdominal muscles acting on the rise of IAP (16). The time lag due to the passage of the pressure wave through the abdominal cavity was negligible (less than 0,00013 s.), and there was no noticeable distortion from the pressure recording system. We have, however, to take into consideration that a pressure rise within the cavity may by itself elicit stretch reflexes from the muscles that make up the wall of the cavity. As for the diaphragm, Newsom-Davis (32) found a mean latency of phrenic nerve conduction in normal adults amounting to $7,7 \pm 0,8$ msec. Assuming an average conduction velocity of 70 m/s for the nerves supplying the anterior abdominal and the pelvic floor muscles we may estimate an overall time lag of 0,01 - 0,02 s. for the monosynaptic stretch reflexes from stimulation to response - and perhaps a further rise of IAP after an electromechanical delay.

Considering our periods of 0,1 s. for integration of EMG and averaging of the pressures, it seems clear from the above that it is impossible to distinguish exactly which muscular activity proceeds and which follows the pressure rise in every instant. It seems, however, possible to evaluate the relative importance of the different muscles around the abdominal cavity.

As for the muscles in the pelvic floor, i.e. the great levator ani muscle that has a dome shaped form, sometimes called the diaphragm of the pelvis, we chose to pick up the activity from the puborectal muscle, which is easy to identify from the ampulla and previously investigated by others (23,38) but not

during lifting. The muscle is known to be activated when straining and coughing.

As intramuscular wire electrodes may be displaced, deformed and fractured during contractions, (24) we preferred to place the wire electrodes outside the muscle but close to it. With an interelectrode distance of about 1 cm we also picked up myoelectrical activity from a greater part of the muscle but yet no continuous activity from the surroundings. The wire were not found to be distorted after withdrawal.

The intrathoracic (ITP) and intraabdominal (IAP) pressures
The following physiological formulas should be considered:

$$1. \text{ ITP} = \text{Palv} - \text{Pel}$$

ITP = the pressure within the oesophagus

Palv = the pressure within the alveols and the trachea

Pel = the lung recoil pressure

Palv is equal to the pressure in the open air when the airway is open, i.e. the glottis is open, except for the small variations of $\pm 0,1 - 0,2$ kPa during natural breathing. Pel is dependent on the air volume within the lungs, varying between about 4 kPa after maximal inspiration to about 0,5 kPa after maximal expiration (17).

The pressure within the oesophagus (ITP) is equal to the pleural pressure on the same level. There is a small vertical pressure gradient with increasing values downwards. The gradient amounts to about 0,4 kPa between the upper and lower parts of the oesophagus (35).

$$2. \text{ Pdi} = \text{IAP} - \text{ITP} = \frac{2 \cdot T}{R} \quad (\text{Laplace Law})$$

P_{di} = the Transdiaphragmatic pressure difference

T = the Tension (active or passive) in the diaphragm

R = the Radius of the curvature of the diaphragm

In this context IAP should really be measured close below the diaphragm instead of the stomach and the ITP close above the diaphragm. The error of P_{di} due to the methods of measurement, maximally about 1 kPa, varied in all the subjects in the same way due to the trunk position, and was disregarded.

P_{di} is zero when the diaphragm is relaxed and rises with increased tension of the diaphragm, whether due to active contraction or passive stretching (8). Grassino et al (14) found a curvilinear relationship between P_{di} and the EMG of the diaphragm during static contractions. Sears et al (37) found a nearly linear relationship between P_{di} and the EMG of the diaphragm during Mueller manoeuvre. The average variation of P_{di} during quiet breathing in the standing position was 0,85 kPa for men, according to Gilbert (13). By the Laplace Law, these variations may, of course, be attributed both to varying tension and to varying radius. It should also be considered that the diaphragmatic muscle obeys the force-length-relationship and produces a higher tension when elongated than when flattened.

3. The abdominal cavity contains mainly fluid and semisolid material and is thus practically incompressible, except for the small amounts of gas that may occur in the stomach and the colon. The walls are flexible, and a muscular contraction somewhere will result in a protrusion somewhere else, if possible, otherwise the pressure will rise quickly.
4. There is always a "force balance" (4) between the intraabdominal pressure and the tensile forces in the abdominal

wall, equal to the Laplace law for the diaphragm. This means that a rise of IAP will necessarily be resisted by an increased tension, active or passive, in the wall and/or by a reduced radius of the curvature of the abdominal wall and the pelvic floor.

The respiration

The different respiration steps in this study did not affect the IAP significantly in any instance, though the oblique abdominal muscles were more activated in some lifts during expiration, with or without facilitation. This might seem surprising, as everybody knows that one should inspire before lifting heavy burdens. The main point, however, is not the phase of respiration, but the closure of the airway, preferably by closing the glottis. This enables us to build up a positive ITP which will support the diaphragm from above and thus diminish the demands on that muscle, by reducing the Pdi. In other words, if the glottis is closed, a higher IAP may be possible with less effort from the diaphragm. This was certainly done spontaneously by fairly many subjects (fig. 9) and should be still more common among the weightlifters, when they do real lifts with a barbell (22).

Compton et al (5) recorded intrathoracic pressures up to 34,6 kPa among two weightlifters performing the "clean and jerk" and investigated the circulatory effects.

By lifting during expiration the abdominal muscle activity increased, which may be due to these muscles' expiratory function especially towards the end of expiration. The activity did not, however, affect the IAP, either with or without facilitation.

Pdi during maximal diaphragmatic effort, i.e. the Mueller manoeuvre, was found to be fairly well correlated to the peak IAP during lifting in the patients but not in the weightlifters. In both groups, there was, however, a very good correlation between the peak IAP and the Pdi during lifting. It thus seemed as though the weightlifters did not use the capacity of their diaphragms wholly.

The building up of the IAP

As for the interplay between the muscles lining the abdominal "ball", it should first be mentioned that there are obviously several ways of doing the same lift (fig. 5). Subject A was a "high pressurizer" with a pretty good co-ordination between the diaphragm, the oblique abdominal and the puborectalis muscles and an ability of the diaphragm to create a high Pdi. Subject B was "expert" at activating the puborectalis muscle, which seemed to be the prime mover, while the diaphragm could not respond to the IAP but gave way. As he had obviously closed his glottis, the ITP increased and thus the whole trunk was pressurized. Subject C, finally, started with a fairly active abdominal muscle but there was only a small peak IAP. Something is lacking, probably the co-ordination, perhaps the capacity of the diaphragm.

Secondly, we may conclude from fig. 6 - 8, that it is possible to influence the mechanism of the IAP rise, although previous studies (18,20,29) have shown, that it cannot generally be accomplished by abdominal muscle training. We cannot say, why the three subjects in fig. 6 - 8 managed to increase the IAP but probably how. The co-ordination before the lift-off seemed to have improved (fig. 6 b, 7 b, 8 b). Perhaps a preprogramme after having performed a great many lifts in our laboratory? Fig. 7 a, and 8 a shows that a high activity of the oblique abdominal muscles only does not suffice.

As for the transverse abdominal muscle, we do not know anything about its activity during lifting. It should be useful for pressurization due to the direction of its muscle fibers, which should make it possible for it to contract without giving any bending moment or spinal compression.

It should be pointed out that the activity of the erector spinae muscle is reduced in fig. 8 b compared to fig. 8 a during the phase when the IAP is elevated. This was seen in a fairly

large number of comparable lifts, and might indicate that the load on the erector spinae muscle was reduced when the IAP increased.

Lastly, the three pairs of graphs in fig. 6-8, gave about the same shape of the acceleration curve for each couple. Nor could we find any differences, when, for each couple, we made comparisons of the curves from the electrogoniometer or of the video records. There were no differences as regards the lever of the box or the lifting time, that might explain the differences in IAP.

The causal factors of the IAP rise during lifting has not hitherto been clarified. Bartelink (2), Morris et al (31), Grillner (16) and others suggested that the IAP increase is due to a reflex mechanism, but the form of such a reflex was not considered. Kumar (26), and Kumar-Davis (28) studied the afferent component and suggested that stretch receptors in either the tendons or the muscular tissue of the erector spinae muscle could be responsible, "if a reflex exists" (28). As for the assumed efferent component of such a reflex, there are, to our knowledge, no studies on the contributions paid by the diaphragm and the pelvic floor muscles. Kumar (26, 27) found a strong correlation between peak IAP and external oblique activity but this does not necessarily mean a cause and effect relationship. Recent studies (11,19) have shown that the oblique abdominal muscles are only slightly activated during lifting as compared to their maximum activity during trunk flexion strength tests. It was also shown that low back patients could produce the same IAP during lifting as healthy controls in spite of a reduced abdominal muscle strength. The result of the present study agrees with the earlier conclusions that the oblique abdominal muscles are of minor importance for the rise of IAP (18, 19, 20).

The rectus abdominis muscle was not taken into account, as it is only occasionally activated during lifts up to 40-50 kg (11, 31).

Conclusion

The IAP rise during lifting seems to be conditioned by a good coordination between the muscles surrounding the abdominal cavity, i.e. the diaphragm, the oblique abdominal muscles, and the muscles of the pelvic floor (the puborectalis muscle). The diaphragm as reflected by the Pdi (transdiaphragmatic pressure difference) seems to be the most important one for the pressure level, as there is significant correlation between the peak IAP during lifting and the maximum Pdi among low back patients and between the peak IAP and the coincident Pdi during lifting among both patients and weightlifters. The oblique abdominal muscles were previously seen to be of minor importance to the IAP during lifting (18, 19, 20), and this study confirms that a one-sided activation of that muscle is not sufficient for an IAP rise during lifting. The few recordings of the pelvic floor muscle suggest that this muscle may be fairly important for the rise of IAP. The transversus abdominis muscle is probably of some importance, but we lack information about it. If the diaphragm is too weak to withstand the pressure from below, closure of the glottis should help pressurizing the trunk. Otherwise the type of respiration seems to be less important in this context. Further studies are needed on the co-ordination of the trunk muscles and to evaluate different means of preventing low back disorders.

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